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Secretary's Letter, Announcements,
Joint I.A.S./C.A.I. Meeting,
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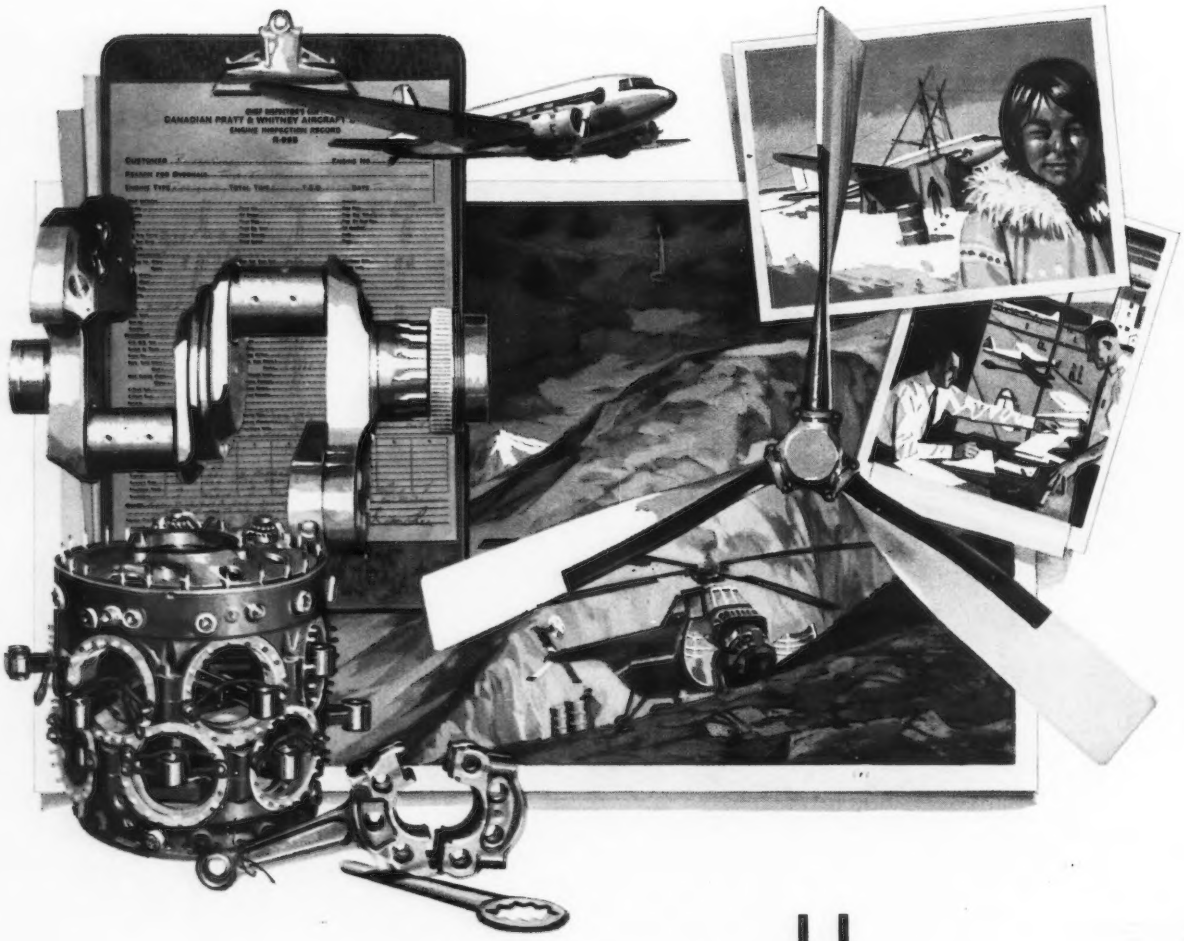

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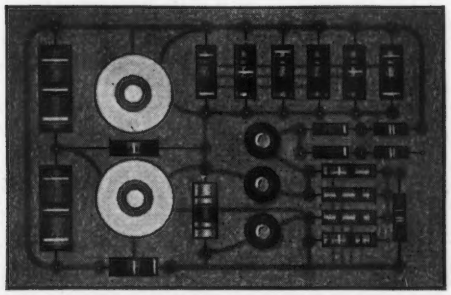

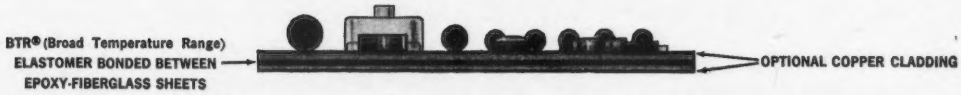

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JOURNAL

R.C.A.F. AIRSPRAY FOR BITING FLY CONTROL†

by A. E. Winmill* and Dr. A. W. A. Brown**

Canadian Forces Medical Service and
University of Western Ontario, respectively

SUMMARY

Approximately 300 sq mi are treated by the RCAF each year with DDT at 0.22 lb/acre to combat blackflies and mosquitoes at various stations. It is concluded that in nearly all cases the airspray routine employed is providing an effective and economical means of control of these biting flies. The method has definite limitations, and should not by itself be considered sufficient to provide total and long-lasting relief. It is of greatest benefit in northern areas where the biting-fly season is intense but of comparatively short duration. In these areas airspray has permitted outdoor activities to be efficiently continued throughout the summer where otherwise they would have been seriously hampered. There has been no evidence of any adverse effects on fish or other wildlife in any area where authorized airsprays have been carried out by the RCAF.

INTRODUCTION

AIRSPRAY operations are carried out to control biting flies either as larvae, that is while they live in water, or later in the life cycle when they mature into adult mosquitoes and blackflies. The object of a biting fly airspray is not, as a great many people assume, the total elimination of all biting flies in any given area; rather it is the quick reduction of an existing heavy pest population to give immediate relief and thus make it possible, through the supporting use of ground fogging equipment and personally applied repellants, to carry out normal military and recreational activities. The number of annual airsprays authorized for a specific location is kept to the minimum which will give adequate control. Airspray is entirely feasible and economic where the season is of comparatively short duration, the area is inaccessible to ground equipment, the fly density is so great that such equipment could not control it without outside support and the total area is too extensive or scattered for effective control to be economically maintained by ground equipment. All of the airsprayed stations fall in this category, with the single exception of an area at Camp Borden which is treated as a training exercise for ground and aircrew personnel in preparation for the full scale operation. At this point it should be emphasized that every precaution is taken to ensure that the fish and wildlife resources of a treated region are not seriously or permanently affected. Representatives of the Canada Department of Fisheries attend the planning meetings in an advisory capacity and concur in the proposed operations before final approval is given to proceed.

ADVANCE PLANNING AND SUPPPLY OF MATERIALS, HEADQUARTERS LEVEL

The initial planning for an airspray takes place at an Ad Hoc Committee Meeting held annually in the fall of the preceding year. This meeting, formerly convened by DGMS(Air) and now by the Surgeon General, Canadian Forces Medical Services, is attended by representatives of the Department of Agriculture, Department of Fisheries, Defence Research Board, RCAF Air Materiel Command and RCAF Air Transport Command. The stations to be airsprayed are selected, and the type of operation, either larvicide or adulticide, together with the area in square miles for each, is determined. In addition, tentative dates are selected for the spray flights, subject to later confirmation or modification by subsequent counts of biting fly abund-

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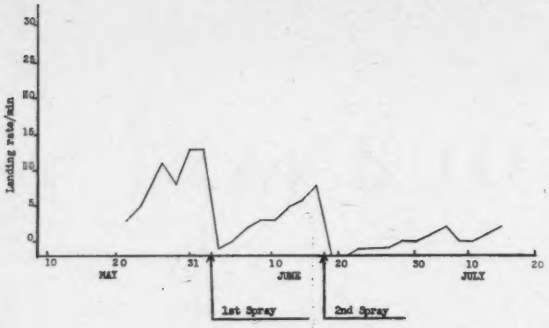

Figure 1
Effect of airspray on adult mosquito landing rate count at Cold Lake, Alta., 1958

ance as the season opens at each station. Each station or unit is then advised as to the type of airspray, extent of area, and tentative dates of the planned airspray, and is requested to submit counts at two-day intervals. These counts are plotted on a graph, similar to those shown at Figure 1, as soon as they are received at Air Force Headquarters, or the Directorate of Preventive Medicine, Canadian Forces Medical Services, which thus has graphs for each station. When the counts indicate that an airspray is imminent, the previously tentative dates are either confirmed, advanced, or retarded, and the units advised accordingly. The individual unit is responsible for all local arrangements, i.e. survey, selection of spray areas, ground marking, mixing and loading of insecticides, provision of ground party and vehicles and the taking of counts. Coordination of the over-all programme, including confirmation of the spray dates, formerly the responsibility of Air Force Headquarters, is now the responsibility of the Assistant Surgeon General 8c, Canadian Forces Medical Service.

In the meantime the problem of supply must be solved. The DDT is provided as a 30% concentrate in oil solution and is diluted with No. 2 fuel oil to 10% for adult and 5% for larval control. The supply and stocking of these materials at various units according to their requirements is the responsibility of RCAF Air Materiel Command. About 285 sq mi (182,400 acres), at twelve separate locations as shown in Table 1, are sprayed each year. The number of airsprays authorized per unit varies from 1 to 3 and may be for either adult or larval control. The areas sprayed range in size from 5 to 20 sq mi. Normally about 25 operations are flown each summer at locations ranging from Goose Bay to Whitehorse and Frobisher Bay to Camp Borden. Positioning the 14,500 gals of 30% DDT and 35,500 gals of No. 2 fuel oil at these sites is a monumental task which must be repeated each year.

HISTORICAL DEVELOPMENT OF AIRSPRAY

The technique for airspraying northern stations was developed by the Defence Research Board in cooperation with scientists of the Canada Department of Agriculture. The history of the experimental steps in the development of the final method is well documented by publication in the scientific journals, and this background material is cited below by number.

TABLE 1
AREAS AIRSPRAYED IN SQUARE MILES

Location	1958		1959	
	Area Airsprayed	Annual Total	Area Airsprayed	Annual Total
Cold Lake	10–20–20	50	10–20–20	50
Whitehorse	20–20	40	20–20–20	60
Mont Apica	5–5	10	5–5	10
Parent	5–5	10	5–5	10
Senneterre	5–5	10	5–5	10
Falconbridge	5–5	10	5–5	10
North Bay	5–5	10	5–5	10
Frobisher Bay	5	5	5	5
Fort Churchill, Bird / Fort Prince of Wales*	20–20	40	20–20	40+
Goose Bay	20–20	40	10–20–20	50
Camp Borden**	20	20	20	20
ANNUAL TOTALS		245		275+

*At the request of the Department of Northern Affairs.
**For training purposes.

The first field experiments were performed in 1947 and 1948 at Churchill, Manitoba, by a joint US-Canadian group. They demonstrated that DDT applied at the rate of 0.25 lb/acre from an RCAF Dakota (DC-3) aircraft would control mosquitoes both in the adult[3] and larval[2] stage. In May and early June 1949, five stations from Goose Bay to Whitehorse were airsprayed at this dosage, using a 4% DDT solution emitted in parallel flight lines 200 yds apart[3]; between 83 and 99% control of mosquito larvae was obtained, and the subsequent adult infestations on these stations was roughly one-half of that in neighbouring unsprayed areas. Therefore in June-July 1950 a similar airspray was applied against the adult insects at Goose Bay, and obtained 86 to 98% control of mosquitoes and 70% reduction of blackflies; 4 weeks after the airspray the mosquitoes were still one-quarter as numerous as in unsprayed areas, but the blackflies had returned to four-fifths of their normal level[4]. In 1951 the effectiveness of the spray was increased by using a more efficient atomization system; a sheaf of propeller-driven rotary brushes (Figure 2) was affixed to the straight emission pipe formerly used. This allowed economy in payload by substituting 10% for the 4% DDT solution formerly employed, economy in flight lines by extending the interval to 300 yards, and overall economy in flying time by achieving coverage of 3.4 instead of 1 sq mi in each spray flight. In addition to these economies, this method gave better control; the initial reduction obtained at Goose Bay was 99% for mosquitoes and 85% for blackflies[5]. The finer atomization also allowed all adulticide application to be carried out at the uniform height of 100 ft, sufficient spread being obtained even in light winds. For larvicide application, however, the straight emission pipe is employed without attachment of the rotary brush. Since the emission rate of the straight pipe is 2.25 gals/sec, which is approximately double that of the rotary brush, it becomes necessary to use 5% solution instead of 10% in order that the dosage rate of DDT should not exceed 0.24 lb/acre.

The routine of airspray was therefore standardized to this method of applying DDT at 0.22 lb/acre, and

Figure 2
Rotary brush and driving propeller in position under fuselage

Figure 3
Free propeller of rotary brush unit, and point of attachment to straight emission pipe

provisional instructions were drawn up in 1953 for use by the RCAF; these proved satisfactory and are incorporated with little further modification in the Interservice Manual on Pest Control[8]. The 10% DDT spray solution is contained in two 275-gal tanks (from the B-25 Mitchell) linked to a single gate valve; this installation, developed by the Suffield Experimental Station, can be put in the Dakota aircraft in 14 man-hours. The spray is emitted from a rotary brush unit (I-C-D Model 851, Campbell, California) consisting of a sheaf of 5 brush-bordered discs turned by a free propeller (Figure 3). When the aircraft is flying at 150 mph, the unit revolves at 2,500 rpm and emits 1.05 gals/sec by gravity feed. The atomized spray shows a median diameter of 97 microns and a mass median diameter of 195 microns. A good proportion of droplets spreads for at least 300 yds cross-track even at height-wind products as low as 200 ft-mi/hr, i.e. at 100 ft flying height and a cross-wind component of 2 mi/hr. In the very rare instances where the wind is very light and on-track, the flying height may be increased. Larvicide operations are carried out at higher wind speeds, necessary to spread the coarser droplets.

Aerial spraying should be performed when the air is largely free of the turbulence caused by vertical convection. On sunny days, the turbulence disappears about 1 hr before sunset; on overcast days, there may be little turbulence all day. Light rain does not render the spray ineffective. The areas to be sprayed should be laid out with regard to the 3.4 sq mi coverage of each flight; the aircraft carries enough spray for 480 seconds of emission, equivalent to 20 mi of flight time. The plots are laid out with parallel flight lines, at 300-yd intervals, approximately 1 mi long or less. These flight lines set off at right angles from a starting line, which is measured on the ground and along which marker stakes are put in every 300 yds. The length of each flight line is calculated as the time taken to fly it; these emission lengths are marked in seconds on the co-pilot's map to provide the direction for turn-on and turn-off of the spray. The direction of each flight is established from the map and specified in degrees magnetic. The entire operation for each station is laid out by judicious juxtaposition of plots, which in an adulticide operation should form a continuous area, but for larvicidal application should be related to the breeding areas.

ORGANIZATION AND PLANNING, UNIT LEVEL

An airspray coordinator is appointed at each station. He is responsible for local arrangements regarding the taking of "counts", mixing of materials, availability of all ground support equipment, ground marking of selected areas, provision of groundcrew and local coordination of the ground and air phases of the operation. Although most of these responsibilities are self-explanatory, some clarification is required on the following two points:

(a) the "counts" which have been mentioned are a representative sample of the insect density at that particular time, and are used as a gauge to determine the optimum time for spraying. The density of infestation of mosquito larvae is sampled in the breeding pools by means of a white enamel dipper; the larvae caught in each dip are counted and their approximate age is determined. The average count per dip, based on numerous dips in preselected pools scattered about the station, is sent to Headquarters for plotting as the larval count for that station. This figure varies from day to day but when it exhibits a decided and continued upswing the spray aircraft carries out the larviciding operation to destroy these insects in their aquatic breeding-places. From this point on adult biting fly "counts" are recorded. These are actual counts of the number of landings per minute of mosquitoes or blackflies on a specified area of an individual's clothing. The species being counted at each unit is as noted in Table 2. They are taken by one person at a number of preselected locations at approximately the same time each day. All figures for each particular station are averaged and sent to Headquarters for plotting as the landing-rate count/min of either blackflies or mosquitoes at that station. As with the larval count, when the trend shows a decided and continuous increase in numbers the spray aircraft proceeds to the station and carries out the adulticiding operation. The

TABLE 2
% REDUCTION OF BITING FLIES FOLLOWING EACH AIRSPRAY OPERATION

Location	1958 Airspray		1959 Airspray		Target
	1st	2nd	1st	2nd	
Goose Bay, Labrador	100.0	100.0	47.3	100.0	Mosquitoes
Parent, Quebec	100.0	75.0	100.0	87.5	Blackflies
Senneterre, Quebec	100.0	–*	70.0	–*	Blackflies
Falconbridge, Ont.	–*	60.0	100.0	100.0	Blackflies
Fort Churchill, Man.	100.0	100.0	72.7	100.0	Mosquitoes
Cold Lake, Alta.	93.3	100.0	100.0	100.0	Mosquitoes
Whitehorse, Yukon	100.0	100.0	100.0	75.0	Blackflies & Mosquitoes

*Count invalidated either because not taken in the 48-hour period immediately following the airspray, or because weather conditions were considered to have been a greater factor in influencing the post-spray count than the airspray itself.

experience and records which have been accumulated over a number of years have made it possible for the Committee, which meets in the preceding fall, to forecast with considerable accuracy the dates upon which airsprays will be required at military establishments in any part of Canada during the following year. In actual practice very little adjustment to the schedule was necessary in either 1958, 1959 or 1960.

(b) the ground marking of selected areas is carried out to ensure that the aircrew can apply the spray evenly and methodically on to those areas where the requirement is greatest, and avoid areas where the application of insecticides would either be harmful or would serve no useful purpose. A large-scale map, preferably one inch to the mile, is used to plot the areas indicated by topographical and "on-site" assessment to require airspray. Each entire area on the map is marked out in parallel lines at 300-yd intervals as described earlier. A corresponding series of marker stakes for flight lines is established on the ground, and a duplicate map is prepared for the aircrew.

AIRSPRAY OPERATION

The actual operation is carried out by one of the two Dakota aircraft which have been equipped for airspray operations. One of these is based in the West, the other in the Eastern section of the country. The equipment, described earlier in the article, allows the aircraft to apply either larvicide or adulticide sprays. The following is a description of a typical airspray operation.

On the afternoon of the spraying operation the 30% DDT concentrate is checked for crystallization and steamed back into solution if necessary. It is then diluted to the 10% finished spray for application by mixing one part DDT concentrate with two parts No. 2 fuel oil in a fuel tender. The solution is then recirculated for about 30 minutes to ensure complete mixing.

On the evening of the spraying operation, if weather conditions are favourable, the 3-man ground party (in a radio-equipped vehicle well supplied with smoke generators, Very pistol and smoke puffs, and an orange coloured marker panel measuring 8 ft × 2 ft) meet with the aircrew at the spray aircraft, which has

Figure 4
Dakota aircraft in flight emitting spray

by that time been loaded with the spray solution. The duplicate map is passed to the pilot who ascertains that it requires no further clarification before takeoff, and the aircraft and ground party radio transmitters are tested for serviceability. If everything is in order, the spraying altitude and starting point is determined and the aircraft takes off, while the ground vehicle proceeds to the starting point.

At the starting point the ground party ignite a smoke generator and set up the marker panel on the first marker stake so that it is readily visible from the aircraft. The generator serves both to guide the aircraft to the starting point and to provide an indication of the amount of wind-drift which can be expected to affect the spray at ground level. The radio transmitter is used to talk the aircraft in to the starting point. The Very pistol is used on request of the aircraft pilot only. At this point the pilot may elect to make a dummy run and check his drift while he flies the first spray run without emitting any insecticide. If this occurs the ground party hold their position until the aircraft comes around for the second time. When the ground party see spray being emitted from the aircraft as it passes overhead (Figure 4) they then proceed along the starting line to the next marker stake and set up the marker panel again. This is continued until the operation is completed, or spraying conditions deteriorate. The aircraft must be flown at an indicated air speed of 150 mph to give the correct dosage and obtain an even coverage of the ground. The directional gyro or radio compass may be used on spray runs, although in some areas accurate map-reading is perfectly adequate. Normally all turns are made to port so that the pilot can see the ground party markers readily. The pilot, since this is a low-altitude operation, concentrates on flying the aircraft. The co-pilot operates the stopwatch on timed runs and indicates, from his copy of the map, the correct time to start and stop spray emission and the correct time to switch from one spray solution tank to the next. A crewman positioned at the valve in the fuselage (Figure 5) carries out these instructions.

R.C.A.F. AIRSPRAY FOR BITING FLY CONTROL

A. E. Winmill and Dr. A. W. A. Brown

Prerequisites for and types of airspray are explained; areas of responsibility and authority defined; evaluation and perfection of military airspray technique from its inception in 1947 to the present; airborne equipment described; safeguards and liaison with other government departments stressed; typical airspray operation outlined and results discussed; costing data provided.

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AIRCRAFT STRUCTURAL LOADS **E. J. Becze**

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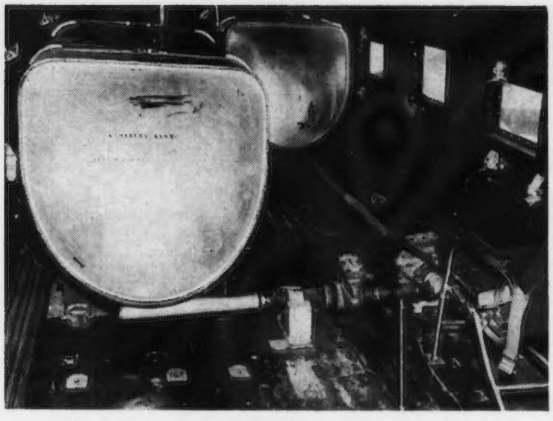

Figure 5
Crewman's position, insecticide tanks, piping and valves

When the spraying operations for any particular day have been completed, the fuel tender is flushed out with approximately 50 gals of fuel oil. The aircraft lands with its spray tanks empty and these are also flushed out with fuel oil if practical.

It is sometimes necessary to modify the foregoing procedure slightly at various stations due to local topographic, climatic or other conditions. No deviation is permitted, however, in the total area to be treated, type of airspray (adulticide or larvicide), concentration and type of insecticide used, or dosage rates. These are factors which have been concurred in by the Canada Department of Fisheries as being acceptable, and if increased might endanger local fish and wildlife populations.

RESULTS

The degree of control which is obtained varies from unit to unit and year to year, but for adult blackflies and mosquitoes, as well as mosquito larvae, it has been generally good. Assessments in 1958 and 1959 showed that 100% reduction of mosquitoes was obtained in 12 out of 16 operations, and 100% initial control of blackflies in 8 out of 13 operations (Table 2). The populations gradually recover after having been decimated by each treatment (Figure 1). The causes of the incomplete control in the minority of operations are attributable to weather conditions, topographic features and local vegetation, which also strongly influence the rate of repopulation.

Larvicidal operations have not been so successful. The reduction of mosquito larvae obtained in 1959 at RCAF Station Goose Bay was only 67% and the adult count rose to 38/min later in the season, as contrasted with 52/min over a corresponding period in the previous year. The first adulticide spray in 1959 at this station was only 47% effective. Larvicidal airsprays applied from a Dakota against blackflies at RCAF Station Mont Apica obtained only 50% control in 1958 and 55% control in 1959. This result was largely due to the mountainous nature of the locale, which has the effect of delaying the date of egg hatching and of increasing the spraying altitude of the aircraft. Control has also been complicated by the dense coniferous forest and by the necessity for extreme caution to avoid harming local fish and wildlife. It appears that the Dakota aircraft is of dubious merit for such operations at Mont Apica, which is the only location where airspray control of blackfly larvae has been attempted by the RCAF. A helicopter has since been made available and has completed two successful spray operations at this station.

In 1958 the adult mosquito landing rate counts from RCAF Station Cold Lake indicated 93 and 100% control following two successive airsprays. Figure 1 shows the effect of two adulticide airsprays on the landing rate counts received from this unit. These figures are not unusual and are a good indication of what can be accomplished with proper training, equipment and co-ordination of effort. The main variable in deciding results is the weather. On the one hand, steady winds following an airspray can bring about the reinfestation of a treated area within a very few days. On the other hand, excessive rain, low temperatures or high winds induce biting flies to take cover, and can cause an illusion of complete control which is quickly dispelled on return of more favourable weather. Under average conditions reasonable control of adult mosquitoes can be expected for as long as 2 or 3 weeks, and for approximately half that time in the case of blackflies. Airspray has not been found to provide effective control of horse flies or deer flies.

EFFECT ON WILDLIFE

Every precaution is taken to protect fish and wildlife. The concern with this matter is carried right back to the planning stage, at which representatives of the Canada Department of Fisheries concur in the proposed programme before it is finally approved. As a result of this excellent co-operation and the strict adherence of all personnel to airspray instructions, there is no evidence that RCAF airspray operations to date have had a deleterious effect on fish or wildlife, despite the fact that the larvae of blackflies and (to a lesser extent) mosquitoes form a large part of the diet of game fish. One of the reasons for this clean record is that much of the larvicidal airspraying is performed over swamps or sphagnum bogs not frequented by game fish. Airspray for adult control has shown no deleterious effect on fish. There have never been any reports of wildfowl or other birds leaving an area because of Air Force spraying operations; it is therefore concluded that the dosage used, averaging 0.22 lb DDT/acre, is causing no harm to wildlife.

COST DATA

In 1959 the basic cost for airspray was $0.247/acre. Of this, $0.062 was for crew and aircraft operation, while the remaining $0.185 was for insecticide and fuel oil, mixing and reloading, ground survey and marking. To this basic figure additional charges ranging from $0.025 to $0.34/acre must be added to cover the expense of ferrying the spray aircraft between its permanent base and the station to be airsprayed. Inclusive costs varied therefore from a minimum of $0.272 to a maximum of $0.587/acre.

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ANNUAL GENERAL MEETING

The Annual General Meeting of the Institute will be held at the

SHERATON-MOUNT ROYAL HOTEL, MONTREAL

on the

14th and 15th June, 1962

The technical sessions will be associated with the theme of SAFETY and are tentatively planned as follows:

Methods of Accident Investigation and Engineering Considerations
(e.g. Investigation techniques, technical causes of accidents, safety provisions in the event of accidents)

Safety in Space Operations
(e.g. Destruction on malfunction, escape from space vehicles)

Operational Causes and Avoidance of Accidents
(e.g. Human factors, training, experience, flight authorization procedures, air traffic segregation)

Members of the C.A.I. are invited to present papers on any of the above-mentioned subjects and anyone wishing to do so should submit a brief summary for consideration by the National Programmes Committee. Such summaries must be in the hands of the Secretary by the 31st December, 1961.

AIRCRAFT STRUCTURAL LOADS†

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THE loads imposed upon the components of an aircraft structure during normal operations or during abnormal conditions all have to be assessed with a reasonable degree of accuracy. The designer is at all times attempting to balance the demands for the attainment of two opposing ends, safety and economy. If the aircraft is to be acceptable to the purchaser, it must be capable of withstanding all loads that it is going to encounter during its service life. If, on the other hand, the aircraft is to be of any value, particularly in the field of commercial competition, it must be capable of reasonably economical operation. The answer to the first problem is to make the structure very strong, while the answer to the second is to make the structure very light in order that more payload may be carried. The two solutions are incompatible. In practice, a compromise has been reached in which it is tacitly assumed that a small percentage of the aircraft of a particular type will, at some time in their normal operating lives, suffer structural failure.

In the earlier days of aviation, there was no attempt to arrive at any criterion for the acceptable failure rates of aircraft. In more recent times, concomitant with the upsurge in the interest in statistics, attempts have been made to use probability theory in conjunction with loading calculations to arrive at a sound and consistent design philosophy. If the operational history of an aircraft could be predicted, if the loads encountered by aircraft structural components during the performance of these operations could be predicted, and if the static and fatigue strength characteristics of the aircraft structural components were known, it should be possible to determine the probable life of the aircraft, taking into consideration structural fatigue and isolated extreme loadings.

Loads can be classified in various ways, e.g. in relation to environment, to interaction of elements, and to manoeuvring and flight envelope. The aircraft has two environments, which are the ground and the air, with the loads encountered in one being different from those encountered in the other. Loadings can be broken up into groups through a consideration of what major elements interact to produce the loads, as, for example, into the interaction of the aerodynamic and structural elements of the system. They can also be divided into loads produced during the different phases of operation of the aircraft, i.e. into a dependence of loads on the manoeuvring and flight plan of the aircraft.

Loads can be considered with regard to the amount of control that the pilot is capable of exercising over their magnitudes. For some forms of loadings the pilot is completely incapable of control, except by evasion of the conditions under which the loadings occur. For example, in the case of the onset of mild control surface flutter the only remedy that the pilot would have, even under the most favourable conditions, would be a reduction of the airspeed. During taxiing the pilot is capable of exercising control over the loads produced to the extent that he can choose the optimum taxiing speed. When making a pullup manoeuvre, the pilot is in theory capable of controlling the loads imposed, except under exceptional circumstances.

A consideration of the loads to be discussed in the present note shows that some of the conditions which impose ground loads on an aircraft can be controlled, so as to minimize their effects, while others are beyond pilot control. Buffet loads are under the control of the pilot to the extent that he can at times regulate the penetration of the aircraft beyond the buffet boundary, and also to the extent that he can make a rapid recovery from the buffet region. Loads encountered in atmospheric turbulence are not under the control of the pilot, except that he can evade some regions of turbulence and that he can reduce speed in regions of extended turbulence. In manoeuvres the loads imposed are supposedly under the control of the pilot, but it has been found that extreme precision is required in rapid manoeuvres and that there are conditions under which manoeuvres become divergent.

Thus, the importance of the pilot's response is greater in some problems than in others and, at present, the various factors that can control pilot response are among the problems receiving close attention in aeronautical research.

The loads problem can be divided into three subcomponents: the forcing function, the admittance of the aircraft structure, and the response. It is the first of these problems that is emphasized in the present discussion.

GROUND LOADS

The landing phase of a flight is one of the most critical, and many accidents occur at this time. There are four stages into which this phase can be subdivided: the approach, the touchdown, the runout, and the ground manoeuvring subsequent to runout. The approach is in theory under control of the pilot, but

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factors are present which tend to make control at this time difficult. Poor visibility is an obvious source of trouble and gusts which affect the lift and sideslip of the aircraft cause varying rates of descent and lateral components of aircraft velocity at touchdown. Another difficulty has arisen with the newer types of aircraft because of the excessive airspeeds required at landing, speeds which may be in excess of 200 mph.

The touchdown is beyond the control of the pilot, all conditions existing at this time having been determined by the attitude and rates of motion of the aircraft immediately prior to the initial contact of the landing gear with the ground.

The runout is again only in part under pilot control, in that he is able to regulate the rate of deceleration of the aircraft by the application of brakes, reverse thrust, and arresting devices such as trailing chutes.

The pilot has control of the aircraft during taxiing in that he is able to decide upon his taxiing speed. When the aircraft is being turned, the pilot has control of the braking forces that he applies and of the radius of the turn. Ground handling and taxiing are also required prior to takeoff.

Associated with each stage of the landing is the type of load which the aircraft structure has to be capable of withstanding. Some indication of the importance of the loads encountered during ground impact, runout, taxiing, and ground handling is given by the fact that the landing gear structure is 10 to 17% of the structural weight of the aircraft and from 5 to 8% of the empty aircraft weight. In addition, many of the remaining structural components are affected by the ground loads, either directly or indirectly. For between 15 and 45% weight of the aircraft structure, ground loads are the critical design criteria.

Early aircraft types were small and relatively rigid and so it was customary to carry out landing analyses on the assumption that the aircraft was a rigid body on a landing gear with known dynamic characteristics. No consideration was given to any loads except impact at touchdown. Because of the lower landing speeds and the high rigidity of the aircraft, there was no apparent need to consider the runout and taxiing loads, even though it is most likely that runways were not nearly as carefully constructed and maintained as they are now.

During the past 20 years changes in the design and performance of aircraft have produced a much more complex dynamic system. Wings have become longer and thinner with a great increase in flexibility; multi-engined aircraft have been developed in which the engine nacelles are placed far outboard and also well ahead of the leading edge of the wing; fuel is stored in the outboard sections of the wing and in external tanks located at or near the wingtips. All of these factors tend to decrease the natural frequencies of the wing structure. And not only is this trend to lower natural frequencies found in the wing, but also in the fuselage and the empennage. Thus it was early recognized that there was no longer a legitimate reason for the consideration of the aircraft as a rigid structure, and various proposals were accordingly put forward to enable the designer to arrive at more rational answers.

The aircraft certifying agencies still tend to consider the landing and ground loads problem in the manner previously favoured. The various possible landing configurations are considered by specifying limit loads to be expected upon impact and by specifying factors of safety to be applied to these loads and to the structural components. These external loads are to be balanced by the inertia forces and moments arising in the aircraft, the forces and moments being applied in a rational or conservative manner. It is nevertheless specified that if dynamic oscillations of the landing gear and structure of the aircraft are significant, they are to be considered because of the possibility of more severe loads being generated in the flexible aircraft than in the rigid aircraft. The load imposing attitudes to be considered are the following: two-wheel landing with the two main gear touching the ground simultaneously, three-point landing, one-wheel landing with one of the main gear touching the ground first, landing in which the aircraft is yawed or is drifting to the side, braked landing, ground manoeuvring, and engine run-up with braked nose wheel and with the aircraft stationary when various combinations of engines are in operation.

Early methods of attempting to account for flexibility in the response of aircraft to impact loadings were based upon the simplifying assumption that the problem could be broken into two stages, the first of which was the calculation of the ground reaction for some assumed velocity of descent on the basis of a rigid aircraft being decelerated by a flexible landing gear, and the second stage being the calculation of the stresses in a flexible structure under the application of known external forces. Thus it was assumed that the flexibilities of the landing gear and the remainder of the structure did not have any influence on the loads imposed by either component upon the other.

One of the first methods to appear was based on a semi-statistical interpretation of the landing impact problem. It was recognized that landings could be represented only on a statistical basis. It was assumed that aircraft flexibility did not have an effect on the time history of the contact force, and that damping and other aerodynamic forces could be ignored. The aircraft response was represented by a system of normal modes of oscillation which were assumed to have been excited by the impact force. To overcome the difficulty of getting a statistical representation of the landing impact forces, it was proposed that the complete envelope of responses to all forms of landing impulses which were to occur be used for each mode, in order that the worst condition could be accounted for in the response of that mode, and that the modes be added together with no regard to phase, to ensure that the worst condition of over-all response could be arrived at. It was argued that, since there was no knowledge of damping, it was feasible to assume that each mode of oscillation would continue to be represented with undiminished amplitude for a long enough period of time that all modes would eventually be in phase to give the worst condition as calculated.

This method was early regarded as being much too conservative, but it was accepted as a method wherein flexibility could be considered in a rational manner. In the evaluation of the envelope of responses to landing impulses, Duhamel's integral had to be worked out for a function which could not be represented analytically – a process which involved considerable labour. This difficulty was soon overcome and, in addition, it was found that fewer modes could be used if the problem were reformulated to express the modes of deflection in terms of a static component and a dynamic component of response.

Whenever the time required for the external loads on a system to build up becomes comparable to the half period of oscillation of the lowest natural mode of the system, dynamic effects become important; and it was found in these early investigations that aircraft had already reached the stage where this requirement was met because of the low natural frequencies of the structure. Thus it was necessary to determine, with considerable accuracy, what the modes of oscillation of the structure were. This could be done by calculations, by model tests, or by full scale resonance tests. Calculations are lengthy and difficult, models are difficult to make to truly represent the elastic properties of the structure, and resonance tests cannot be made before a prototype of the aircraft is built, to say nothing of the difficulty of measuring the pure natural modes of the structure, even when the prototype is available. Thus, the construction of large flexible aircraft creates a considerable difficulty in the analysis of the structure for the effects of landing loads.

Proposals have been made that would remove the requirement of using normal modes in favour of the use of coupled modes, in order that fewer modes could be used with a resultant saving in computational effort. One ambitious programme was suggested in which the aircraft would be represented by six rigid body freedoms together with wing bending and torsion, fuselage bending and torsion, and stabilizer bending and torsion. However, because of the difficulty involved in computation, it is customary to consider wing bending as the only flexible degree of freedom, even though it is recognized that wing torsion might be of importance because of the high drag forces produced at the base of the landing gear strut by the spin-up of the wheels at initial touchdown.

Five years ago it was proposed that the landing impact problem be considered as a nonstationary random process. Through an experimental study, the force on the landing gear is found as a time dependent probability distribution, although in theory a statistical knowledge of the rates of descent of the aircraft would be sufficient to give the required landing gear force probability distribution. When the landing gear force probability distribution, $f(t)$, is known, the response at any point 'x' at any time 't' is given by the formula

$$y(x,t) = \int_{-\infty}^{\infty} \frac{A(\omega)}{Z(x,\omega)} e^{i\omega t} d\omega$$

where $A(\omega)$ is the Fourier transform of $f(t)$, and $Z(x,\omega)$ is the impedance of the system, that is $1/Z(x,\omega)$ is the admittance or steady rate response of the system under excitation by a steady unit sinusoidal forcing function $e^{i\omega t}$ of frequency ω. The statistical moments $\overline{y^n}(x,t)$ can be computed by an extension of the above formula and, when these moments are known, it is possible to determine the probability of exceeding any given stress in the structure. One of the difficulties in this method is the determination of the impedance of the system, and since the impedance must be derived from a linear system of equations, it would be difficult to include the effects of the landing gear because this structure is nonlinear. Nevertheless, it is theoretically possible to arrive at a stress envelope which represents the maximum stress at any point of the structure. This would enable the entire aircraft to be designed to a uniform factor of safety with respect to landing impact loads, but it is doubtful that this method would ever be used in its entirety because of the prohibitive amount of labour that would be involved.

A comprehensive analysis of the landing impact problem has been made for the case where the flexible structure and the nonlinear landing gear are considered to interact with each other as a system of coupled equations of motion. The nonlinearities of the landing gear, including damping dependent on the square of the velocity of travel, nonlinear air compression, and exponential tire force-deflection characteristics, have been considered. In addition, the considerable nonlinearity due to the precompression of the air in the oleo-strut has been accounted for. Because of the nonlinearities, the solution had to be obtained by a numerical step-by-step integration method. It was found that, for a large aircraft, load reductions of the order of 15% can be experienced by the landing gear because of flexibility. However, a rather unfortunate result of this study was the discovery that, for one large aircraft, the loads in the structure were increased while, for another, they were decreased. This was apparently an effect of the ratio of the time of impact to the natural frequency of the structure. Thus it would appear that it is impossible to generalize as to results to be expected on any particular aircraft, and that the only method by which reliable answers can be obtained about impact stresses is through tedious computation.

Theoretical analysis of the case of one-wheel landings has shown that, under certain conditions of aeroplane configuration, the impact load on the second wheel to touch the ground can be greater than the load on the first wheel, with the consequence that the energy absorption of the second gear has to be considerably greater than that of the first. This phenomenon is due to the rate of roll produced by the impact of the first gear which has to be overcome by the second gear. In addition to possible initial rates of roll, side drift can be present. This puts added loads on one of the gears, but not always on the one to touch ground last. Statistical flight studies have shown that the second wheel to contact ground has usually a higher impact velocity, but a dependence on aircraft configuration which was predicted is not shown.

The phenomenon known as negative drag is caused by the sudden fall-off of the drag force which is principally due to spin-up of the wheels. The drag force causes the gear and wing to deflect in such a manner as to allow the wheel to move aft, but when this force is abruptly removed at the completion of spin-up the gear springs forward. It has been found from measurement that the forward component of force is at times of the order of 80% of the maximum drag force. It is possible for the peak structural load due to this force to coincide with peak loads due to other causes, and in this event high loads may result. Drag damping produced by sweepback of the landing gear appears to be effective in the control of negative drag difficulties.

A problem, sometimes referred to as walking, can also arise due to skidding of braked wheels on wet runways in which a fore and aft force is generated in phase with the oscillation of the landing gear. During one series of measurements it was found that this force increased to four times the average drag before the brakes could be released. Just as for negative drag, sweepback of the landing gear is effective in the control of this problem. Also, anti-skid devices have not proved to be entirely satisfactory.

Brake chatter, which is due to the intermittent slipping of brake surfaces, has a similar effect to skidding on wet runways. In one instance the chatter forces were equal in magnitude to the spin-up forces, and it was found that this was sufficient to reduce the fatigue life of the gear one one-twentieth of the expected value.

Many papers have been written on the problem of shimmy, but because of conditions such as looseness, tire conditions, friction, and damper nonlinearities, the problem is difficult to handle, and so design is still largely arbitrary with the major consideration being the maximum available absorption of energy. Test rigs are not too difficult to construct so that testing for shimmy could be done in the laboratory.

One field of ground loading in which virtually nothing has been done is in the study of loads imposed during ground handling operations, such as turning.

There remains one aspect of the ground loads problem to be considered, namely that of taxiing loads. About five years ago the notion of the power spectrum was introduced as a method of studying taxiing loads. The term 'power spectrum' is a carryover from the field of communications engineering, where it is used as a method of specifying what portion of the energy in a signal lies in a particular frequency band; but as now used it may have no connection with energy. The runway roughness in terms of elevation variations which are considered as consisting of a superposition of sine waves of different wavelengths is expressed in terms of a power spectrum.

$$\phi_n(\omega) = \frac{C}{\Omega^2}$$

where C is a constant and $\Omega = \frac{2\pi}{L}$ where L is the wavelength of sine wave under consideration. The spatial frequency is changed to a time dependent frequency ω by the introduction of V, the forward velocity of the aircraft, so that the spectrum becomes

$$\phi_n(\omega) = \frac{CV}{\omega^2}$$

The response power spectrum of the aircraft component under consideration is given by the relationship

$$\phi_o(\omega) = \frac{VCT^2(\omega)}{\omega^2}$$

where $T(\omega)$ is the admittance of the system. This predicts that the response of the system is linearly related to the forward velocity of the aircraft. Tests have shown, however, that this relation is reasonable only at low aircraft velocities, and an explanation is given that the presence of a threshold below which the oleo-strut does not deflect dynamically produces the nonlinear effect. As is well known, this poses a problem which is difficult to overcome.

Nevertheless, the importance of taxiing loads could not be ignored because not only did pilots complain but it was found that, under some conditions, these loads were of similar magnitude to loads at the positive manoeuvring load factors of the aircraft. Increased aircraft flexibility, increased taxiing speeds, increased taxiing distances, the presence of external fuel tanks and overhanging jet engines had resulted in structural failures and adverse controllability during taxiing. On a rough runway the accelerations at the centre of gravity of an aircraft may reach 1.5 g while the accelerations at the wing tips may be eight times as high. In some studies it was found that a large portion of the high taxiing loads was imposed at taxiing speeds of less than 20 mph, even though higher taxiing loads had been expected at the higher speeds. A puzzling development was the discovery that, even though the frequencies transmitted by the landing gear were between 1.5 and 2.0 cps (frequencies well below the resonance frequencies of the structure) the frequencies measured at the wingtips were considerably higher.

There are two possible methods of determining load occurrences during taxiing. One is the representation of the aircraft on an analogue computer, a method which has the advantage of permitting the representation of landing gear nonlinearities. The other is the solution of the problem by generalized harmonic analysis, which assumes a normal distribution of runway disturbances and a linear structural transfer function. Although the assumption of normality of runway disturbances is open to question, and it is known that the transfer function is not linear, certain advantages of the generalized harmonic analysis approach make it the more promising method. These advantages are: the classification of runways as to roughness is facilitated; the runway forcing function is presented in concise form; the possibility is present for the establishment of a representative runway profile; the application of many runway inputs to one aircraft is facilitated.

Thus, the power spectral method is proposed on the basis of an argument that the shock strut is linear over a limited range of operation, and because the effects of aerodynamic damping can be taken into

account, although with difficulty, by the calculation of the transfer function over a range of velocities. If the computational problems are accepted, the problem can be formulated in the form

$$\phi_o(\omega) = \phi_i(\omega)\,|T(\omega)|^2$$

where $\phi_o(\omega)$ is the power spectrum of the response at frequency ω, $\phi_i(\omega)$ is the power spectrum of the runway disturbance, and $|T(\omega)|$ is the absolute value of the admittance of the system. If the distribution is assumed to be normal, that is with a Gaussian distribution, the probability of exceeding any specified value of response can be calculated, and the effect of taxiing on fatigue can be evaluated.

Fatigue is probably the most critical aspect of the landing loads problem because of more refined design, because of the use of high strength materials with relatively less fatigue resistance, and because of more utilization of the aircraft. Unfortunately, the present method of fatigue analysis is at best only approximate.

The Structures Laboratory of the National Aeronautical Establishment has been carrying out a programme of determination of the power spectra of runways in Canada, as part of a programme initiated by the Advisory Group for Aeronautical Research and Development of the North Atlantic Treaty Organization. Recently, the Structures and Materials Panel of AGARD arrived at a specification for runway profile deviations. For new construction, the maximum recommended deviation in 80 feet of runway is 0.5 inch, while old runways may be allowed to have a deviation of 0.9 inch in the same distance. The recommended deviation over a 200-foot length of runway is 0.75 inch for new construction and 1.3 inches for old runways.

BUFFET LOADS

Buffeting is the term given to the phenomena involving irregular air flow, resulting from various conditions of flight and also to the loadings experienced by the structure of the aircraft when these flow conditions exist. There are two principal regions into which the complete range of flying conditions producing this irregular flow can be conveniently divided, the stall buffet and the shock induced buffet. In the first, the aircraft is in a manoeuvre in which such a high angle of attack is produced that the air flow over the lifting surface breaks away, with the result that the wake of the lifting surface becomes turbulent. This breakaway occurs at the maximum value of lift that the surface is capable of producing, and the aircraft is said to have stalled. Shock buffet first occurs at aircraft velocities approaching the speed of sound. Any sudden change of flow direction over aerodynamic components may combine with compressibility effects of the air to produce regions over which shock waves form, the wake again being turbulent. In manoeuvres during which the lifting surfaces assume high angles of attack with respect to the relative wind direction, stall occurs; the important distinction between this form of stall and the low-speed stall being that even when separation occurs at the higher speeds it does so first over localized regions, so that there can still be a considerable increase of lift over that value at which separation first occurs.

Buffeting is a condition which is to be avoided because of several of its effects. In fighter aircraft the structural vibrations can seriously detract from the effectiveness of the aircraft as a gun platform. The vibrations, if they are present for any significant period of time, are a contributing factor to fatigue of the crew, to say nothing of the annoyance which they would cause for passengers if the aircraft were an airliner. Also, if the fluctuations are of large magnitude, the question arises as to whether they are of sufficient magnitude to cause significant fatigue of the structure or even immediate failure. These reasons for the undesirability of the presence of buffeting cause service limitations to be placed on aircraft, either as limitations on the maximum severity of maneouvre that may be executed or as maximum permissible speeds of flight, or combinations of both.

Obviously, if the presence of buffet is to be discovered only when the aircraft is already in service, much of the intended range of operation or of manoeuvre performance may have to be excluded. This may be very wasteful of structural material and of engine power, or the aircraft may simply be unsatisfactory for the purposes for which it was intended. Thus it is desirable to be able to predict the regions in which buffet difficulties are to be expected.

In 1930 the potential difficulties to be expected from buffeting were expounded by Duncan, but during the intervening years not too encouraging results in the field of buffet prediction have been obtained. An indication of the present view on the problem is given by the design requirements of the various aircraft certifying agencies. One American agency gives as qualifications on buffeting the requirement that there shall be no buffet condition in normal flight severe enough to interfere with aircraft control, to cause excessive crew fatigue, or to cause structural damage to the aircraft, although buffet as a warning of stall is to be considered a desirable feature. There is no mention of calculations.

Although there has not as yet been developed any really satisfactory method of predicting the onset of buffet or of the magnitude of buffet to be expected, there have not been many failures, probably because it is inherent in the nature of buffet that the pilot is given some warning of the onset of buffet which allows him to correct the condition, and partly because buffet loads appear to build up with time. It must be noted, however, that an indeterminate amount of damage due to buffet may be a contributing factor in accidents in which structural failures are attributed to entirely different causes.

Several approaches to the problem of estimating buffet loads have been tried. One of the earlier theoretical methods was dependent on the assumption that buffet was caused by a sinusoidal vortex street, that is the forces on the wing were due to the presence of a vertical sinusoidal fluctuation of velocity of the air through which the wing was passing. However, it was found that even in the ideal case of a cylinder passing through a stream of air at moderate values of Reynolds number, a condition under which the wake is supposed to consist of vortices with a regular frequency, the

actual wake consisted in part of the vortices of expected frequency and in part of vortices with a continuous distribution of frequencies. Since the response of an elastic structure is dependent to a very great extent on the degree of correspondence between the frequency of the forcing oscillation and the natural frequency of oscillation of the structure, it was recognized that this method of analysis could not give any reasonable results.

Another method of attacking the problem is the collection of statistical data from flight tests to find what parameters have an effect on the buffet loads. It was thought that, once sufficient data had been accumulated, trends might appear to indicate the effects of the various parameters which were considered to be of importance. This method has not been of great assistance in an assessment of the buffeting problem because of the excessive number of parameters on which buffet loads have been found to be dependent. It cannot be denied that even though this method will not yield quantitative answers, it still can act as a valuable guide to designers, especially if the design under consideration is not of a radically new form.

The wind tunnel has often been of value to the designer, and so an attempt was made to study buffeting by this means. There are four possible uses of the wind tunnel for this purpose: determination of the buffet boundary of a particular aircraft; measurement of the fluctuations in the wake of a model, which is a first step in the determination of its power spectrum; measurement of loads on the model; the assessment of the effects on buffet of various specific structural and contour modifications. It has been found, however, that in some instances measurements have been made virtually impossible because of tunnel turbulence. In general it has been found that wind tunnel measurements of buffet loads are difficult to make and, once made, they are only with difficulty related to the full scale aircraft. Viscosity and compressibility of the air are fundamental to buffeting and therefore the Reynolds number becomes of prime importance in a comparison of tunnel measurements and full scale measurements.

If the loads are to be measured directly on a model in a wind tunnel, the question arises as to whether the model should be rigid or flexible and, if it is to be flexible, how important it is that the structural modes of vibration of the full scale aircraft be accurately represented by the model. Since not too much is known of the wake structure of a buffeting aircraft, it would seem to be necessary, in order to ensure against possible errors caused by flexibility effects, to duplicate the structural modes of the full-scale aircraft to a considerable degree of accuracy. This is, however, a very difficult problem. It has been found that, of the total tail buffeting load, only a small component is produced by the motion of the tailplane, the remainder being produced by the changes in effective angle of attack resulting from the turbulence in the wing wake. Thus, if it could be proven that the turbulence structure is not affected by the aerofoil structural deflections, the need for accurate representation of the full scale structure would be diminished.

The use of rigid models would have the advantage that it would be known when measurements are carried out that these measurements are generally applicable to all aerofoils of the same profile. The trend of experimentation may be turning in the direction suggested, i.e. to the measurement of the wake of a rigid wing and to the measurement of the pressure fluctuations over a rigid tailplane in the wake of the rigid wing.

The most obvious use of the wind tunnel is in the study of the effects of specific structural features on the buffet performance of an aircraft. This is, at the present time, the most profitable method of combating the buffet problem from the point of view of the manufacturer.

The characteristic buffet traces obtained from flight tests show a high degree of irregularity, with here and there a sudden large amplitude oscillation of several cycles duration, and then possibly almost no response for a period of time. This is a characteristic shown by a lightly damped elastic system under the excitation of a random force. Ten years ago it was first proposed that the methods of generalized harmonic analysis be used in the study of buffeting. Accordingly it was proposed that buffet be considered as the response of an elastic system to an aerodynamic excitation which could be considered to be a stationary random process, i.e. a random process for which the mean values are, over the long run, independent of the time.

The basic equation of the power spectral method of analysis is

$$\phi_o(\omega) = A^2(\omega)\, X^2(\omega)\, \phi_i(\omega)$$

where $\phi_i(\omega)$ is the input power spectrum of turbulence, $X^2(\omega)$ is the absolute value of the square of the admittance of the wing, $A^2(\omega)$ is the absolute value of the square of the admittance of the elastic structure, and $\phi_o(\omega)$ is the power spectrum of the output.

Attempts have been made to carry through buffet calculations using the concepts of isotropic turbulence. A turbulence field is in general three-dimensional. It has been usual to assume the condition of isotropy, i.e. the condition of turbulence in which the mean values of the fluctuations in any coordinate direction are independent of rotation of and reflection of the coordinate axes. For this type of turbulence, measurements have been carried out and have yielded an expression which is not too unwieldy and which can be conveniently approximated. Unfortunately, little is known of one of the parameters – the scale of turbulence. One of the benefits of the method proposed of using rigid models for the measurement of the wakes of aerofoils would be that information would be obtained on the characteristics of turbulence, without having to interpret the response of an interacting structure.

The admittance of the wing can be calculated with the benefit of a few approximations, including the assumptions that disturbances occur in the direction perpendicular to the wing only, and that rates of change of turbulence are small with respect to the rate of forward motion, to give an expression which

is in itself quite complicated but which can be approximated reasonably by a simple expression. This, however, is for the simple case of a two-dimensional wing, and when the finite span of the surface and the differences of phase between different sections of the aerofoil are considered added problems arise.

The next question that arises is whether elastic effects are to be considered. It is not known how the wing buffet load is affected by the flexibility of the structure, but from measurement it was found, in one instance at least, that rear fuselage and tail flexibility were responsible for only one-third of the tail buffet load. The question arises as to which modes of the structure are required in the analysis if a reasonable estimate of the buffet load is to be arrived at. For straight-winged aircraft, it has been generally assumed that the first wing bending mode alone will give a reasonable representation of the structural flexibility, and it has been found from experiment that the major effect of flexibility is due to this first mode. For swept-winged aircraft, at least a coupled first bending-first torsion mode seems to be required. It seems that in tail buffet, the important modes are the rear fuselage torsion mode and the first stabilizer bending mode.

In theory as many modes of the structure can be represented in the expression for the admittance of the flexible structure as are desired, but in practice the number of modes chosen is limited by the unwieldiness of the expression and by the fact that the higher dynamic structural modes of deformation are not known with an adequate degree of accuracy.

The output power spectrum is thus obtained by a complex operation; the data required for each stage of the operation being at the present time known with only doubtful accuracy. When the power spectrum of the output is known, all the desired information about the problem is not yet available. The mean square output, $\overline{y^2}$, is related to the input quantities by the relation

$$\overline{y^2} = \int_0^\infty A^2(\omega)\, X^2(\omega)\, \phi_i(\omega)\, d\omega$$

where y may be a deflection, load, or other quantity depending on the formulation of the problem. Obviously, a knowledge of the mean square value of a loading is of little value when maximum values are required and when information on fatigue is needed. It has often been assumed that the response follows a normal distribution. If this is the case, the frequency of occurrence of peaks of any magnitude can be predicted, as can the number of times per second that the load will cross the zero value. Both of these predictions are required if an estimate of the fatigue damage due to buffeting is to be made.

Considerable data on aircraft buffeted deliberately in flight are available. From these data an estimate of the value of the power spectral method of buffet load prediction is possible. It is known from experiments that at higher Reynolds numbers the regular character of the wake of a model disappears and it becomes completely random. It has not yet been adequately proven that the buffeting of an aeroplane is completely stationary or completely normally distributed. From some tests it appears that the wing buffet loads are normally distributed and random, but that the tail loads are neither stationary nor normally distributed. The assumption of a normal distribution is of considerable consequence because, if there is an error in the distribution function, the extrapolation required in the prediction of the maximum loads becomes extremely doubtful.

Thus at the present time, considerable experimental investigation is required to enable the method of power spectral analysis to be used with confidence. Not only is the legitimacy of the primary assumption still in doubt, but in addition too little is known of some of the auxiliary relationships, e.g. that defining the input turbulence spectrum. The flight studies carried out have, however, given considerable qualitative insight into the problem. It has been found that wing buffet loads are not as large in proportion to the design limit loads as are tail buffet loads. An increase in sweepback has been found to be beneficial in the alleviation of buffet problems. Several devices, including wing vortex generators and mechanical dampers on the wing tips, have been found to be of some value in reducing buffeting loads.

The solution of the general buffet problem is, it may be seen, still in a very unsatisfactory state, and much research is required in this field. Recording of information in a number of buffeting manoeuvres has been completed at the NAE with a view primarily to the study of spanwise correlation of flight buffet loads. The aircraft used is a straight-wing fighter and the instrumentation consists of strain-gauge installations at three spanwise stations of the horizontal stabilizer.

LOADS IN TURBULENCE

The air masses over the surface of the earth are in continual motion. Unstable conditions can exist which are so severe as to give high rates of shear in the eddies produced in any one of a number of ways. These instabilities can be of large scale, with rates of wind shear which are not so great as to affect too noticeably the forces or accelerations on an aircraft which is flying through them, or they may be more localized, with such high rates of shear as to produce significant forces and accelerations on the aircraft. In this latter case they are classified as gusts.

The gust problem was early recognized as one which deserved careful study because of the high stresses that could be produced in an aircraft structure encountering a severe gust. Not only is this a problem of aircraft static strength but also one of structural fatigue, of aircraft controllability, and of crew and passenger discomfort. As civilian aircraft became larger, the strength requirements in terms of the number of g that the aircraft was required to withstand in manoeuvres were reduced. At the same time the aircraft speeds were continually increasing, with the result that for a gust of a specified magnitude the new aircraft types would be subjected to higher loads than the old. Both of these factors made design for gusts important. Also, the change to large, more flexible structures with stores in the wings and with large

external overhanging masses raised the possibility of difficulties with dynamic responses. One benefit to the modern aircraft is that arrived at by the increase in the altitudes of flight, since there is a reduction in the number of gusts of high equivalent vertical velocity encountered at the higher altitudes. The development of radar for storm identification has enabled the pilot to avoid areas of high turbulence to some extent.

Various methods have been developed for alleviating the aircraft responses to gusts, but in general the degree of success has not been too encouraging.

The first attempts to calculate the effects of gusts were made before 1920. The concept of a 'discrete gust' was introduced, i.e. it was assumed that each gust could be taken as being independent of any other turbulence occurring at the same time. The aircraft was considered as being rigid and the transients associated with the buildup of forces and moments on the wing entering the gust were neglected. This resulted in a system of ordinary differential equations.

Later, the transient nature of the buildup of the forces and moments was allowed for by the use of the operational calculus, the equations taking the form of integral equations which could be solved by inversion. The gusts were assumed to be of various types: discrete sharp-edged gusts, discrete gusts with a ramp-like buildup of vertical velocity, discrete gusts with a sinusoidal buildup of vertical velocity, and continuous harmonic gusts. Aircraft flexibility and the stability characteristics of the aircraft could be allowed for.

During the last 10 years, the concept of generalized harmonic analysis which was discussed in connection with landing loads and buffeting has been applied to the gust problem. The gust is no longer considered to be discrete, but rather a part of a stationary random process of turbulence which is defined by its power spectrum. If the power spectrum of the turbulence is known and if the admittance of the wing and that of the flexible aircraft structure are known, the output of the system can be determined. If the response is considered to be normally distributed, the peak values likely to occur can be found and the fatigue life of the aircraft in this form of turbulence can be estimated.

Whether the discrete gust assumption or the power spectrum representation is used, the difficulty is that of determining what is a good representation of the turbulence likely to be encountered in the atmosphere. In the case of the discrete gust, the quantities needed are the shape of the gust, the length of increasing vertical gust velocity, and the maximum vertical velocity of the gust. For the power spectral approach, the distribution with frequency, the intensity of turbulence in the form of the mean square vertical velocity of the turbulence, and the scale of the turbulence as an indication of the size of the eddies in the turbulence are required. For either method much data are still needed if the atmosphere is to be reliably represented.

The aircraft certifying agencies at the present time tend to make use of simple formulae to determine the response of the aircraft, the gust velocity to be designed for being specified together with an alleviating factor to take account of the aircraft response characteristics.

Data on the state of turbulence of the atmosphere have been collected by aircraft, by balloon soundings, and by the use of meteorological towers. Tower methods are limited to the collection of data on only the first few hundred feet of the atmosphere. Balloons are capable of providing data only on the general large scale air movements, but they can give these data for a wide range of altitudes. Aircraft are equipped to give data either in the form of the number of times that particular values of normal acceleration are exceeded, with no regard being given to the temporal distribution of these occurrences, or in the form of continuous time histories of normal acceleration. Once the numbers of peak accelerations are determined, these values have to be converted into values of vertical gust velocity if the data are to be of value for general design. This is done by reversing the process of calculating responses to gusts. In addition it is possible, by assuming the turbulence for a given weather condition to be Gaussian and by assuming a spectral shape, to calculate the turbulence spectrum once a value for the scale of turbulence is available and the admittance of the aircraft is known. This method would in theory make it possible to derive power spectra from the great masses of data obtained by the discrete acceleration counting method, but it has apparently been felt that more assumptions would be required than would give confidence to the method. The continuous recording method makes it possible to make the calculations for the discrete gust and also for the power spectra of turbulence. More recently a method has been devised in which a vane is used to give the components of turbulence directly, in order that the aircraft response characteristics need be considered in a simple form only.

At the present time the great majority of the available gust data is in the form of the probability of encountering discrete effective gusts of different velocities in a variety of weather conditions. Power spectra of atmospheric turbulence have been calculated for near ground level by means of tower measurements, and for altitudes up to a few thousand feet by means of aircraft measurements, but the amounts of available data are far from sufficient.

Various causes have an influence on the type of turbulence in the atmosphere. The magnitude and direction of the wind with respect to terrain features, the altitude above the mean terrain, and the general terrain characteristics have an influence upon the turbulence at the lower altitudes. Atmospheric stability and the general weather conditions, such as fronts, have an effect for a wider range of altitudes.

When the gust data are considered in the form of the number of discrete gusts encountered, these terrain and atmospheric characteristics together with local atmospheric conditions, such as the presence of thunder storms, should be directly associable with the number of gusts encountered. It is unfortunately difficult to make such a comparison because of the absence of a continuous time history. When gust data are collected in the form of continuous turbulence data, these same factors need again to be noted, but if, in addition, a complete analysis is required, other characteristics

of the turbulence must be studied. The power spectra of the component velocity fluctuations must be calculated; the degree of homogeneity of the turbulence, the stationarity of the turbulence, the degree to which the velocity fluctuations of the turbulence can be approximated by a normal distribution, and the degree of isotropy of the turbulence must be determined. Turbulence encountered by an aircraft is said to be homogeneous if the nature of the turbulence does not change with different selections of the origin of the record of turbulence. It is said to be stationary if the nature of the record does not depend upon time. Isotropy means that the nature of the turbulence is independent of the direction of flight through the area of turbulence.

The degree to which each of these characteristics is displayed must be determined for every type of turbulence condition, in order that the degree of reliability of the use of the different approximations of power spectral analysis be known. The different patterns which must be considered are low level turbulence where the terrain has a definite effect, turbulence in cloud, turbulence in thunderstorms, clear air turbulence, mountain wave turbulence in the immediate vicinity of ranges of mountains, and jet stream turbulence in areas of high wind velocities.

Thunderstorms have very well developed patterns of large scale flow on which are superposed smaller eddies of turbulent flow. They are generally 5 to 10 miles in width and they extend to altitudes between 30,000 ft and 60,000 ft. Updrafts of 84 fps and downdrafts of 79 fps have been measured at an altitude of 25,000 ft in one instance. Theoretical analysis has indicated possible updrafts of over 200 fps. Superimposed on these large scale air currents are systems of gusts, some of which have velocities of 40 fps. There are an estimated 44,000 thunderstorms on the earth every day but, due to the highly localized nature of the disturbance, pilots are usually able to take appropriate action. It is doubted that thunderstorms will be capable of analysis by power spectral methods.

Turbulence in cloud is of a different nature to that in thunderstorms, in that the area covered by turbulence may be much greater. There is no reason to suppose that stationarity and homogeneity will not be achieved in this turbulence pattern. This type of turbulence is of more importance to the short-haul aircraft because the percentage of time spent by this type of aircraft in the lower atmosphere is much greater than that spent in this region by the long-haul aircraft, which is usually flying above the clouds. It is estimated that for such aircraft only 10% of gust loads are imposed during cruising flight. At the present time spectra are available only for altitudes below 10,000 ft.

Mountain waves are set up on the windward and leeward sides of mountain ranges when there is a prevailing wind in the transverse direction. A standing wave pattern is set up on the windward side, while in the lee of the range there is an extended region of turbulence. Little has been done on the measurement of the turbulence in these areas.

Clear air, high altitude turbulence poses a problem because an aircraft can encounter it without any previous warning, the nearest clouds being as much as 20,000 ft below. This type of turbulence has been experienced by aircraft flying near thin bands of cirrus clouds which are normally free of gusts. Most cases are found in the troposphere, i.e. at altitudes less than about 35,000 ft, but some cases of clear air turbulence have been noted in the stratosphere up to altitudes of 60,000 ft. This form of turbulence is characterized by a rapid succession of equal positive and negative gusts of not too great a magnitude, the highest recorded gust velocity being just over 20 fps. The turbulent areas are usually from 500 to 2,000 ft in depth, up to 40 miles in width, and from 50 to 100 miles in length in the direction of the wind. This clear air turbulence is often found over mountains during conditions favourable to the formation of mountain waves and in regions near jet streams. There are at present no power spectral data available, but it is thought probable that this form of turbulence will be amenable to power spectral analysis, although it is believed that the energy distribution is much different from that in other forms of turbulence.

There are no data on jet streams in the form of power spectra, but there are some in the form of data on wind velocities encountered. Longitudinal shear rates of 530 fps per mile have been measured at altitudes between 32,000 ft and 50,000 ft during the winter and spring, and normal shear rates of 320 fps per mile have also been measured. The shear rates in the summer and fall are somewhat smaller. These high wind shears are generally found in the vicinity of the tropopause but they can be found at altitudes between 30,000 ft and 80,000 ft. In one instance wind shear rates of over 800 fps per mile were encountered at an altitude of 75,000 ft over Japan.

Turbulence near the ground is a result of both mechanical and convective activity. In stable air the mechanical activity predominates, the major factors being wind velocity and ground topography. In both kinds of turbulence the ratio of the vertical component to the horizontal component increases with altitude. The spectra of all components show a systematic shift with height. In particular, the spectra of vertical velocities show that with an increase in height the long wavelengths become more pronounced. It appears that the most predominant wavelength in the spectrum is four times the height above the ground. At the moment there are numerous conflicts in the data available. Some researchers have found that the turbulence at low altitudes is stationary, homogeneous, and locally isotropic, while others have found the opposite results. Also it has been found by some that the velocity distribution is Gaussian except for the peak values, while one researcher found that the distribution followed a modified Bessel function, a result of considerable consequence because the modified Bessel function gives a much greater probability of high velocities.

Tower and aeroplane measurements have been compared to check the assumption that turbulence measurements made at a stationary point in a moving field are the same as measurements made by a moving aircraft in a fixed field. It has been found that tower and aeroplane measurements agree well for the wave-

lengths less than 1,000 ft. The analytical spectra for the longitudinal component and the cross component of turbulence have been used as approximations to the measured spectra, but it appears that at low altitudes the agreement between the spectra is not satisfactory.

It is evident that at the present time the amounts of data are extremely limited. There is inadequate altitude coverage. For the spectra that are available, the range of wavelengths is inadequate since it is estimated that wavelengths up to 60,000 ft are of importance. There is little information on the variation possible in the mean square velocity fluctuation, which is one of the fundamental parameters in the power spectral representation of turbulence. And there is still doubt about the appropriate value to be used for the scale of turbulence, although a value of 1,000 ft appears to be representative.

The more important method of estimating gusts is still the discrete gust assumption, for which much data have been accumulated. Once an adequate knowledge of the frequency of gust occurrences in the various turbulent conditions is known and the frequency of occurrence of these conditions is known, it should be possible by analyzing the missions of any aircraft to make estimates of the gust history of the aircraft, and from this gust history to make estimates of the fatigue life of the aircraft.

The Structures Laboratory of the NAE is, at the present time, obtaining data on two aircraft in the form of discrete count accelerometer readings. Photographs are taken at 4-minute intervals of instrumentation, from which is obtained the number of accelerations experienced in different ranges of normal acceleration, the airspeed, the altitude and the weight condition of the aircraft. This does not give as complete information as a continuous trace, but the amount of data reduction is considerably less than for a continuous trace.

MANOEUVRING LOADS

The final form of loading to be considered is that due to pilot imposed manoeuvres. It would appear at first sight that this problem is considerably more simple than the ones discussed in the previous sections because of the identifiable input forcing functions. Nevertheless, it has been found that there is a very large possible variation in the form of the pilot's input forcing function, and in fact, at the present time, many years after the first attempts at solution of the problems, there is still much doubt as to the correct forcing functions to be used. In addition to this problem of forcing functions, several problems have arisen in recent years from the changes in aircraft types developed for modern high speed and high altitude use.

Manoeuvres can be imposed for a variety of purposes. Military aircraft have to be capable of taking evasive action in the event that they are being pursued by hostile aircraft, while the pursuing aircraft likewise have to execute manoeuvres during the tracking of the targets. These manoeuvres could be turns, pullups, or rolling pullouts. Commercial aircraft would place much less severe demands on the manoeuvring requirements of an aircraft under normal operating conditions, the most probable manoeuvres being banked turns. All aircraft need a reserve of maneouvring capability for the possible emergency conditions of collision avoidance. There is some claim that aircraft need to execute yawing manoeuvres during landing.

If the performance of an aircraft is to be satisfactory over a wide range of speeds, it becomes necessary to design for control surfaces that will be more than adequate for the required performance over at least part of the operating range of the aircraft. Thus the possibility always exists that the pilot will at some time execute a manoeuvre that is so severe that the structural strength of the aircraft will not be sufficient to withstand the aerodynamic and inertia loads imposed. This has the effect of making the manoeuvring loads problem one of estimating the probabilities of the pilot imposing loads too severe for the aircraft structure. Only through the collection of large quantities of data is it possible for the designer to predict with any degree of accuracy the maximum control deflections, the rates of control deflection, and the combinations of simultaneous deflection of different controls which are possible.

There is a persistent demand for reduction of the structural weight of the aircraft in order that more economy of operation be attainable, but this reduction of weight must not be achieved by jeopardizing the safety of the aircraft. As more rational methods of analysis have been made available to the designer, he has been able to give answers that he feels represent the actual conditions encountered by an aircraft in executing a manoeuvre, but unfortunately he is still incapable of feeling reasonably certain that the manoeuvre selected for investigation will be representative of the most severe manoeuvres to be executed (by the pilot of the aircraft). Much statistical information has been gathered and, from this, it has been attempted to construct specifications of maneouvres which will not be exceeded in severity during any reasonable operation of the aircraft. However, it is continually being found that these limits are either so severe that there is an excessive structural weight penalty, or, on the contrary, that the limits are being exceeded with resultant structural damage to the aircraft.

One method which has been proposed is the use of automatic control devices to restrict the severity of manoeuvres to values which do not endanger the structural integrity of the aircraft. Examples of this form of device are normal acceleration limiters and rate of roll limiters. A strong argument for this form of control is the removal of the arbitrary nature of control input which is now possible. It is however argued that the pilot would not be satisfied with the operation of an aircraft which is only partly under his control in cases of emergency, such as possible collision. This argument is of value only if the control device is such as to give an excessive margin of safety. It would be of little benefit to the pilot to evade a collision by breaking off the wings of his aircraft, and besides it might be possible to arrange systems in which the pilot would be capable of over-riding the control through the use of extreme control force. Automatic control is already a necessity in some ex-

tremely high performance aircraft because of the impossibility of the pilot's response being sufficiently rapid. It is probable that, with the development of reliable control devices, many of the current wide variations of pilot control motions will be eliminated even on more conventional aircraft.

The rigid aircraft has six degrees of freedom, which are the three displacements along the cartesian coordinate axes directions and the three rotations about these coordinate axes. The equations of motion of the aircraft had been derived fairly completely by the time of the First World War, but since the complete system of equations was much too cumbersome to use in actual calculations, future effort was directed to methods whereby computations could be facilitated. Symmetric manoeuvres could always be considered separately from the complete system of equations, because in this form of manoeuvre the only degrees of freedom which were affected were forward translation, vertical translation, and pitch. If, however, there was any lateral movement, yaw, or roll, the aerodynamic forces and the inertia cross terms served to couple these so-called asymmetric freedoms with the symmetric freedoms. Nevertheless, because of the prohibitive amount of labour involved in the calculation of responses using six degrees of freedom, it was customary until recently to divide aircraft responses into the symmetric and the asymmetric categories. The distinction is valid for the major part of the present discussion.

As has been said, symmetric manoeuvres affect forward translation, vertical translation, and pitch. Thus, it would appear that a system of three differential equations would have to be considered for the simple case in which structural flexibility and control circuitry are not considered. For ease of calculation, however, it is usually considered to be permissible to disregard changes in forward velocity, with the result that a system of two differential equations is normally used. In addition, the other simplifying assumptions which are of most significance in facilitating computation are the assumptions that stability derivatives can be considered to be linear in the calculations, and that the effects of unsteady flow phenomena can be neglected.

The various procuring services are still not in agreement on the methods to be used in the assessment of horizontal manoeuvre effects. One procuring service specifies that analysis is to be carried out in a rational manner with various assumptions being made as to shape of the elevator forcing function, while others do not insist upon a complete analysis but rather on the use of statistical information obtained from previous flight test measurements. The tail load required to produce a specified pitching angular acceleration is added to the balancing tail load over a range of normal accelerations. What is common to all procuring services is the method of specification of the expected range of normal accelerations to be encountered by the aircraft during its operating life.

The range of normal accelerations, which it is necessary to consider in the study of the symmetric manoeuvre history of the aircraft, is given in the form of a V-n diagram. Operational requirements, human capacity, and gust considerations have, over a period of time, determined the requirements of particular types of aircraft as to the number of g that have to be withstood by the structure over the range of operating airspeeds and altitudes of the aircraft. This V-n diagram is largely a product of much statistical information on the actual loadings encountered by different aircraft during what can be considered to be normal operation.

The symmetric manoeuvre problem has not been changed to a great degree by the advent of the modern high performance aircraft. High altitude flight has resulted in a decrease in the available aerodynamic damping; the high static margins of swept wing aircraft flying at the high subsonic Mach numbers have resulted in different response characteristics; the high inertias of large aircraft have increased their response times; and the differences in design have reduced the relative significance to the no-lift pitching moment coefficient. All of these factors serve to emphasize different aspects of the problem, but they have not really introduced anything that was not present in the early days, except perhaps the effect of low aerodynamic damping which allows for a large degree of dynamic overshoot.

Three major difficulties were present in the calculation procedures for symmetric manoeuvres: the determination of what is to be used as an input forcing function, the measurement of the various aerodynamic parameters which appear in the equations of motion, and the solution of the equations of motion. Until the effects of compressibility became important in the late 1930's, aerodynamic coefficients were either calculated or estimated from flight test results. Compressibility effects made it almost imperative that the coefficients be measured in a wind tunnel. The problem of determining the form taken by the elevator forcing function was largely bypassed by the use of arbitrary elevator input functions in the equations of motion. Most of the effort went into determining methods that could yield solutions with a reasonable amount of effort.

Early methods of solution made use of the operational calculus. The forcing function was specified in analytical form in order that a simple solution could be obtained. If the forcing function used was of an arbitrary shape, the solution was obtained by means of Duhamel's integral. About 20 years ago harmonic analysis was introduced into the calculation of responses to autopilots and into the calculation of aerodynamic stability coefficients. Tabular and graphical methods were developed for different forms of elevator input. One method of solution specified the load factor time history as a function of the load factor aimed for, another assumed it to be approached exponentially, and a third method expressed the load factor as a polynomial function of time. Later a proposal was made that, due to the relative degree of stability in the shape of the normal acceleration time history, it would be better to assume a representative shape for this and to work backward to the time history of the elevator input. The 'inverse' method was

also advantageous in that the solution was no longer a process of integration of differential equations, but instead one of differentiation of algebraic equations. The modern high inertia, low aerodynamic damping aircraft were found to have dynamic overshoots of the order of 50% during the execution of pullups and, in order to take this new phenomenon into consideration, extensive charts of solutions of the equations of motion have been prepared for purposes of ready evaluation of this dynamic overshoot.

All these methods have the inherent limitation that they do not take account of the possible extremes of forms of elevator input to a sufficient degree.

While these attempts at solution of the equations of motion in a rational manner were being developed, another method of evaluation of structural loads was being followed. This consisted simply of the collection of statistical data on the time histories of pertinent quantities in pullups and checked pullups. It was argued that, once the angular accelerations attained in manoeuvres could be predicted with accuracy, it would be possible to assess the magnitudes of the peak loads which could be considered as being produced in part by the angular acceleration and in part by the balancing of the pitching moment produced by the normal acceleration force. The value of the normal acceleration was assumed to be known from the specified V-n envelope of the aircraft.

This method of solution has what is inherently the same difficulty as that of the rational method, in that now no longer are the variations which must be considered those of the elevator input function but those of the resultant output of the system. It is obvious that in either method there is a wide range of possible variation simply because of the inherent differences in response of different pilots, and even of the same pilot under different stimuli or under the same stimulus at different times.

Various formulae have been proposed to give estimates of the angular accelerations to be expected in manoeuvres. The weight of the aircraft, the airspeed, the normal acceleration permitted by the flight envelope, and various other parameters are used in different ways in these formulae. The only thing that is proven by a study of the formulae is the present state of uncertainty in the estimation problem. Several formulae differ in their estimates of the normal acceleration by a factor greater than two to one.

It has been found that if the normal acceleration can be estimated with accuracy, the results of the simple method of tail load calculation, in which the total load is broken into a balance component and a manoeuvre component, give answers quite comparable to those given by flight test. Solution of the equations of motion gives answers which are at times within 10% of the measured values of tail load, but which are in other cases considerably in error. It has been found that the main difficulty is in the estimation of the stability coefficients, and it is claimed that accurate wind tunnel results can ensure good results.

There is yet another method of calculation of responses which is in reality an extension of the rational method first discussed. The actual dynamic response of elevator control circuitry is represented by another equation of motion, and the primary forcing function is taken to be the actual pilot effort instead of the elevator angle attained. It is argued that by this means one of the variables, namely the response of the elastic control circuit, is accounted for, and it is also claimed that pilot effort should not vary as much as some of the other quantities used as forcing functions.

A discussion of some of the factors which contribute to the wide variation of response which is observed may be of interest. In the first place, the manoeuvre can be executed by applying a moderate amount of elevator and holding it for a long time, or by applying an excess of elevator and removing it shortly before the desired value of normal acceleration is reached. In the latter case dynamic overshoot becomes very important. Timing is of great importance, as is seen by the fact that a normal acceleration of 6 g can be attained within half a second of the application of elevator on some aircraft. It is obvious that if the pilot holds the stick for a fraction of a second too long he can overload the structure. The pilot may build up mental restrictions on the rate of movement which limit his response to lower values, if he is aiming at a predetermined value of normal acceleration; when he is free to follow his own will he may consequently apply elevator more rapidly. This would not be easily discovered, because in flight test work he has a predetermined goal in mind. Some pilots have a psychological limitation on elevator rate of application at high speeds which is not apparent with other pilots. Finally, the wide range of altitude and airspeeds over which a modern aircraft may be required to operate makes it difficult to design an elevator control that has the right ratio between stick force and elevator angle over the whole range of operation. In fact power controls are commonly used on high speed aircraft and on large conventional aircraft. Thus, the pilot has the capability of overloading the structure at the lower speeds. Artificial feel can be used and variable boost can be installed into power control systems. But this is just one method of automatic control which does not completely remove pilot variability.

It is likely that in future more consideration will be given to the limitation of manoeuvre severity by means of automatic control, especially if the demand for lighter aircraft structures is to be met.

As has been mentioned, the response calculation of an aircraft has been customarily divided into symmetric response calculations and asymmetric response calculations. The degree of freedom used in asymmetric calculations are roll, yaw, and lateral translation. Just as for the symmetric case, the first attempts were ones in which everything was assumed to be adequately represented by linearized equations of motion with constant coefficients.

The vertical tail is loaded in the offsetting of yawing moments in curved flight, in the deliberate sideslip and fishtail manoeuvres during landing, in rolling pullouts, and in general loadings created during faulty efforts to retain zero sideslip. There have been several design changes which affect the loads experienced by the vertical tail of an aircraft. The pitch and yaw

moments of inertia have become large with respect to the roll moment of inertia with the development of the long, densely loaded fuselage. The progressive reduction in lift slope of the fin with supersonic Mach number leads to loss of directional stability. As the fuselage fineness ratio increases with respect to the size of the fin, the vortices shed by the fuselage at high incidence reduce the effectiveness of the fin. Flight at high altitudes has resulted in a decrease in the available aerodynamic damping.

The early methods of tail load calculation in yawing manoeuvres were simplified to the extent that only sideslip and yaw were considered. Later study of this simplified system showed that there was considerable error in the vertical tail load if roll was neglected in calculations on swept and delta wings. Inclusion of the rolling degree of freedom increased the accuracy of calculations to a satisfactory degree. One method consisted simply of considering the angle of sideslip, the rudder angle and the dynamic pressure, the sideslip in rolling manoeuvres being given by a simplified expression depending on the aircraft mass parameters and aerodynamic parameters. This was a satisfactory method for aircraft of the World War II era but not for anything more modern. It was found that the simple methods often greatly underestimated the sideslip under some conditions and that, if a fishtailing motion was introduced at the yaw resonance frequency, small rudder deflections were capable of producing very large vertical tail loads. In the '40's, lateral motions were studied more extensively and the methods of harmonic analysis were introduced. From the various studies, it has been concluded that use of the three linearized lateral degrees of freedom with linear stability derivatives is sufficient to give quite satisfactory answers in all asymmetric manoeuvres which do not involve excessive angular excursions.

With the advent of the new configurations of aircraft, which were characterized by fuselages which were long and dense in comparison with the wings, it was realized that a new problem which was inherently nonlinear might arise. In the equations of motion considered as a whole with the longitudinal and the lateral degrees of freedom combined, it is found that there are cross-coupling terms containing products of angular velocities multiplied by inertia coefficients, and also products of a linear velocity and an angular velocity multiplied by a mass parameter. The major physical significance of these design changes was the increase of the pitching moment of inertia with respect to the yawing moment of inertia, and the great increase of both of these inertias with respect to the rolling moment of inertia. It was now possible for these inertia coefficients to combine in such a manner that there would be a resultant violent manoeuvre, which might or might not be divergent. In addition to the inertia changes in the modern aircraft, there was also a tendency for the directional stability of the aircraft to decrease at the higher Mach numbers. The net result of these phenomena was the introduction of a new field of possible manoeuvres, in which the pilot would be completely unable to predict what his response would be over part of the speed range of the aircraft under various manoeuvring conditions.

Whenever a problem has to be taken as being nonlinear, the difficulties of solution are greatly increased, with the only methods of solution being in most instances a step-by-step numerical solution of the differential equations of motion or a solution of an analogue computer. For every case which has to be solved, this presents a computation problem which usually requires access to a digital computer or to an analogue installation. The greatest problem, however, is the impossibility of constructing solutions which are known to hold in the general case. This difficulty resulted in an attempt to consider the problem as being capable of a linear interpretation. The roll rate in the equations of motion was taken as being a constant parameter, with the result that stability boundaries could now be found which could be used as criteria for the design of aircraft, and for the limitation of the manoeuvres entered into.

It is now generally maintained that the only way of tackling these nonlinear problems is by a complete solution of the equations of motion.

One of these nonlinear phenomena is the rolling pullout in which initiation of a rolling manoeuvre during a pullout manoeuvre results in a series of oscillations in pitch and yaw which produce high negative normal accelerations and excessive sideslip. The severity of the manoeuvre depends upon the initial normal acceleration of the aircraft, the abruptness of application and removal of control, the maximum rate of roll achieved, the moments of inertia of the aircraft, and the stability parameters of the aircraft.

Various methods have been tried to solve this problem. It has been found that an increase in the coefficient of pitching moment with vertical translation is beneficial, provided that the directional stability coefficient is increased at the same time. The most important parameter seems to be the directional stability coefficient, and this coefficient can be increased to some optimum value by increasing the size of the vertical tail. Little can be achieved by relocation of the masses of the aircraft in the fuselage. Automatic control devices have been studied. It is possible to provide sensing veins in pitch and yaw which initiate control movements sufficient in magnitude to keep the pitch and yaw excursions near zero. A multiplier can be used to feed back the product of two of the angular velocities into the control circuits. Pitch and yaw dampers have been used, the pitch damper being somewhat more beneficial, but neither damper is sufficiently positive in its effects to be of great use. The stability augmenters in general require extreme control deflections which result in large structural loads. In addition, problems arise because of the need to change the feedback in the augmenters as the altitude and speed change during a flight.

Another undesirable manoeuvre which may be produced by gyroscopic forces during rolling manoeuvres is the autorotational roll, which takes place when the incidence of the principal inertia axis is sufficiently negative. In this case the rolling manoeuvre is destabilized in itself. This type of manoeuvre has not

yet appeared in flight, but it is thought that the next generation of aircraft will be subjected to this type of instability.

Pitchup, a condition which is produced by the loss of longitudinal stability of the aircraft over part of the incidence range met with in flight, results in the aircraft assuming an angle of attack which is higher than that desired. Since the lift curve slope of the aircraft is not reduced by a change in the slope of the aircraft's pitching moment coefficient, the increased angle of incidence will result in high loads. Pitchup is not an asymmetric manoeuvre but it is mentioned here because it presents the same problem of nonlinearity as asymmetric manoeuvres. As with rolling pullouts, an attempt has been made to use damping as a method of curing the problem and it has been suggested that, since both result in pitching velocities which are undesirable, a common method of solution may be found.

The procuring services specify that asymmetric manoeuvring loads be calculated by balancing inertia and aerodynamic forces in a rational or conservative manner. Particular rolling conditions are specified as acting together with different conditions of normal acceleration. This makes it essential that rolling pullouts be considered carefully as part of the design criteria. Yawing manoeuvres are considered also, but in this case it is likely that the use of the three lateral degrees of freedom is sufficient.

As in the study of symmetric manoeuvres, in the study of asymmetric manoeuvres the major difficulty is still in the ascription of representative pilot efforts. The collection of much statistical data may be an answer to the problem, but it is believed that only through more use of automatic control will it ever be possible to design for efficient and safe structures.

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ERRATUM

to Vol. 7, No. 7, p 262, September 1961

SOME THOUGHTS ON A NAVIGATIONAL SYSTEM FOR A MACH 2-3 TRANSPORT

For the caption to Figure 1, substitute the following:

Turn errors in aircraft heading induced in the flux valve of a gyro magnetic compass when flying at 450 and 1500 kts with a rate of turn of 6°/min.

Under the sub-heading (*a*) *Turning error*, after the formula

$$E_h = V\,w/g \text{ (tan mag lat) (cos mag track)}$$

for

w = magnetic turn rate in degrees per second

substitute

w = aircraft turn rate in degrees per second

RCAF Stn. Winnipeg W/C K. R. GREENAWAY

CANADIAN AERONAUTICAL
INSTITUTE

C.A.I. LOG

SECRETARY'S LETTER

CANADIAN AERONAUTICAL JOURNAL

This is the last issue of the Canadian Aeronautical Journal. Next month it will adopt the new name "Canadian Aeronautics and Space Journal". Though it is unlikely that the new name of the Institute will have been officially approved by then, it is desirable that we should introduce the change in the name of the Journal at the beginning of Volume 8. We can call the Journal what we like and so a little jumping the gun is not out of order in this respect.

TEST PILOTS SYMPOSIUM

The event of the month has been the Test Pilots Symposium, held on the 17th and 18th November. A full report will be given in the next issue, but I can say now that it went according to plan, in spite of a threat by the weather, which almost prevented the field trip. Last year the Test Pilots Section had a perfect day at sea, aboard HMCS Bonaventure, on the 29th November. I suggest that in future years they should hold their symposia in some other month; they cannot always win this annual gamble with the November weather.

INVITATION TO PRESENT PAPERS

I would draw members' attention to the notice of the Annual General Meeting which appears on page 354. This notice gives a broad outline of the technical sessions arranged by the National Programmes Committee in connection with that Meeting, and invites members to submit papers, within that outline. It is the Institute's job to develop Canadian speakers and to foster the habit of presenting papers, which is regarded in other countries as an important part of a man's professional life. The practice is not so well developed here – to the detriment of the profession as a whole.

I am sure that many of our members can contribute something to the broad subject of Safety – one might almost say that, if not, they have no business to be in the aerospace business – and I hope that we shall get some volunteers.

BRANCHES

Vancouver—17th October

G/C Burton, RAF, who participated in Exercise Skyshield flew from Plattsburgh, N.Y., to Vancouver to address the Vancouver Branch on the 17th October. The meeting was held in the Frazer Arms Hotel and 36 members attended. G/C Burton's subject was "Vulcan MK2, Operations and Handling Characteristics" and although obviously he was restricted in what he could say about this aircraft, he gave a most informative description of its flight handling, engine-out performance etc. He also referred to the countermeasure systems protecting the aircraft against fighters and missiles, crew duties, navigational aids, and operational readiness and dispersal of aircraft. A fairly comprehensive survey and a thoroughly good evening.

Montreal—18th October

The speaker at the Montreal Branch meeting held at Dagwood's Restaurant on the 18th October was Mr. Secor D. Browne, President of the Browne and Shaw Co., Waltham, Mass., an engineer, a linguist and a recognized authority on international civil aviation. His subject was "Aeroflot – Soviet Civil Aviation" and his talk was most informative and very well received. There were 51 members present.

Quebec—12th and 25th October and 15th November

The Quebec Branch has been very active and held three meetings in little more than a month. On the 12th October, at Laval University, they were addressed by Mr. J. P. Beauregard of Canadian Pratt & Whitney Aircraft, who spoke on "The Design and Development of a 500 shp Turbine". Mr. Jackson, the Branch Secretary, reports that it was a good paper but that the attendance was disappointing.

On the 25th October the Branch held a Dinner meeting at Laval University, attended by 22 members, at which Dr. G. N. Adams of Canadair gave an excellent and witty paper on the subject of "VTOL Aircraft".

Finally, on the 15th November, again at Laval University, Lt. Col. J. A. Stairs of the Army Equipment and Engineering Establishment spoke on "The Measurement of Distances in Space". This was a fascinating subject – and his talk did nothing to promote the idea that space travel is just around the corner!

Ottawa: Student Section—6th November

The Student Section of the Ottawa Branch is located at the Royal Military College, Kingston (it is about time it had another Section located in Ottawa) and, in October, O/C T. A. Spruston was elected Chairman, O/C D. S. Poole, Program Director, and O/C P. R. Sanderson, Secretary. They started their season with a flourish, with an address by the President, A/C W. P. Gouin, on the 6th November; there were 36 cadets present on this occasion.

The President's address looked forward over the next ten years and outlined the probable trends in STOL/VTOL aircraft, the development of the supersonic transport and the future possibilities of space explorations. A number of questions were raised from the floor at the conclusion of his lecture.

Finally the session ended with the showing of two colour films on the aerodynamics of transonic and supersonic flight.

Edmonton—8th November

"RCAF Air Transport Operations" was the title of the talk given by G/C W. K. Carr before the Edmonton Branch on the 8th November. As usual the meeting was held in the RCAF Officers' Mess, Kingsway; there were 31 present. G/C Carr outlined the development of Air Transport Command from its start, with Dakotas, to its present Yukons. He showed some excellent slides of aircraft and of various operations from the Arctic to the Congo, to illustrate his account of the part played by the Command within the RCAF and in support of United Nations activities.

Toronto—14th November

There were 92 members present at the Toronto Branch meeting on the 14th November to hear Dr. S. G. Hooker, Technical Director (Aero), Bristol Siddeley Engines Ltd. This was the first visit of a tour made by Dr. Hooker, which took him to Montreal and Ottawa on the following evenings. He spoke on the subject of "Engines for VTOL Aircraft" – specifically on the BS-53 Pegasus – using the now famous "Bristol type" slides and showing two very impressive films of the engine and the Hawker P 1127, in which it is installed.

Halifax-Dartmouth—14th November

The November meeting of the Halifax-Dartmouth Branch was held in the Wardroom, HMCS Shearwater, and heard Dr. G. N. Adams of Canadair present the paper, already mentioned, which he had delivered before the Quebec Branch in October. There were 35 members and guests present and the meeting opened with a short discussion of Branch business and the plans for a two-day Educational Symposium in February.

Dr. Adams traced the history of VTOL, from the early balloon flights to the present day, and stressed the importance of VTOL not only for operational reasons but as a safety measure. He concluded by describing some of the research now in progress to evolve practical and effective VTOL machines for both civil and military use.

SECTIONS

Astronautics

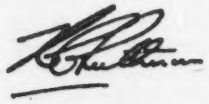
I have recently seen an outline of the programme of Discussion Evenings arranged by the Montreal Group of the Astronautics Section. Unfortunately I do not have all the particulars of time and place but meetings will be held on the 6th February and the 6th March and I suggest that anyone interested should get in touch with Dr. H. J. Luckert, the Group Chairman, at Canadair.

Propulsion

The Propulsion Section is busy arranging the programme of a two-day symposium to be held in Ottawa on the 19th and 20th February. Details will be published in the next issue.

CHRISTMAS AGAIN

With the closing of Volume 7 of the Canadian Aeronautical Journal, I take the opportunity to send you the best wishes of the CAI Headquarters staff for a happy Christmas and an aeronautical and spacious New Year.



ANNOUNCEMENTS

NEWS OF MEMBERS

F. W. M. Moore, A.F.C.A.I., has assumed the responsibilities of Secretary, Bristol Aero-Industries Ltd., Aviation Services Division, Montreal.

E. N. Atkey, M.C.A.I., has left Vancouver to take up a position with the Transport Division of The Boeing Company, Seattle.

D. A. Dixon, M.C.A.I., was recently appointed Director of Aircraft Manufacturing, Canadair Ltd.

W. S. Haggett, M.C.A.I., was elected Industries Vice-President at the recent AITA Annual Meeting.

R. Millington, M.C.A.I., formerly with Canadair Ltd., has taken up a position as Engineer Design with Vertol Div., The Boeing Co., at Morton, Pa.

A. M. Parry, Associate, was elected president of the B.C. Aviation Council at its annual conference.

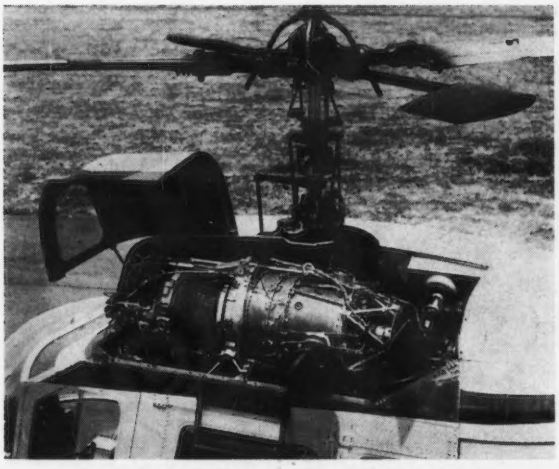
DEATH

It is with deep regret that we record the death of **H. D. L. Gordon, Student,** who was attending the University of Toronto.

SUSTAINING MEMBERS

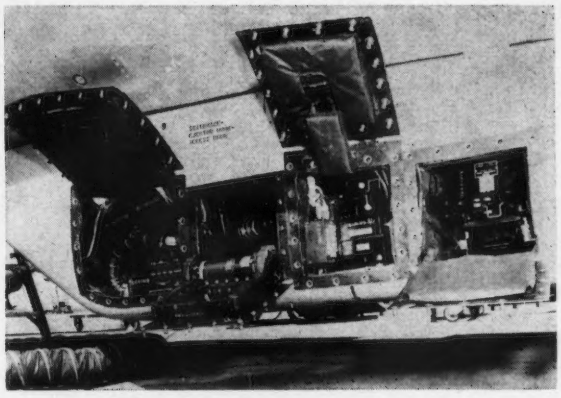
Canadian Pratt & Whitney Aircraft Co. Ltd. has announced the conclusion of an engineering agreement with Kongsberg Vapenfabrikk of Norway, under which the two companies will collaborate in developing non-aircraft applications of the PT-6 gas turbine engine, particularly in the marine field. An immediate application resulting from the agreement is the installation of the PT-6 in a high speed cruiser, the design of which is virtually completed; a prototype will be ready for trials in Norway next year. With this engine, speeds of some 45 kts are confidently expected.

Another application of this engine is its use in the Hiller "Ten99", six-place helicopter. This aircraft is essentially a light utility helicopter, though it has a payload in excess of 1000 lb. The PT-6 engine is well suited to this installation and is reported to be performing very well in this promising new aircraft.



The PT-6 installation in the Hiller "Ten99"

Computing Devices of Canada Ltd. has released some details of their VICOM installation on the CF-104. Flight tests of the prototype Photographic Reconnaissance Pod, designed by Lockheed to accommodate the VICOM system, were carried out successfully in October and the resulting photographs were said to be of excellent quality. The VICOM system has been developed by W. Vinten Ltd. of England and CDC. It is an advanced system for low-level high-speed reconnaissance, which records navigational data on each frame of the 70 mm film. In its present form positional data taken directly from CDC's well-known Position and Homing Indicator (PHI) is recorded, but the equipment is capable of recording other types of data as may be required for photographic identification purposes. This capability is coupled with automatic



The VICOM belly-pod installation on the CF-104

exposure control and such features as in-flight processing of the film and image motion compensation.

Incidentally the PHI has been selected by the RAAF for installation in their new Mirage fighters.

Garrett Manufacturing Ltd. has begun production on a large order of ground support vehicles to service the CF-104 aircraft. The units will provide compressed air for engine starting and electrical power for ground checkout of various systems, all mounted on a sound alternated trailer-type vehicle. The source of power is a gas turbine produced by the Garrett Corporation's AiResearch Division; this will drive a 60 kva alternator generating a 400 mph, 115/208 volt, three-phase electric output or 100 amp, 28 volt direct current and, in addition, 110 lb/min of bleed air is available to turn over the J.79 engine.

COMING EVENTS

BRANCHES

Montreal

17th January—7.00 pm; HOLIDAY INN; *Agena Satellite*, R. Smelt, Lockheed.

Ottawa

17th January—8.00 pm; UNIVERSITY OF OTTAWA; *Magneto-hydrodynamic Propulsion*, Dr. P. Savic, NRC.

Edmonton

10th January—8.00 pm; RCAF OFFICERS MESS, KINGSWAY; *USAF 3955 Sqdn (SAC) Operations*, Lt. Col. G. F. Glick, USAF.

13th February—8.00 p.m.; RCAF OFFICERS MESS, KINGSWAY; *Helicopter Maintenance and Operations*, Speaker from Okanagan Helicopters Ltd.

Halifax-Dartmouth

23rd-24th February—*Symposium on Education*, Details to be announced.

SECTIONS

Propulsion

19th-20th February—OTTAWA, Details to be announced.

JOINT I.A.S./C.A.I. MEETING

The annual Joint Meeting with the IAS was held in the Chateau Laurier, Ottawa, on the 23rd and 24th October, 1961, and, for the first time in the series, its programme was based on a central theme – Aviation in the Polar Regions; all the technical sessions and even the Dinner Address were associated with this topic. The result was attractive and the total registration of 212 (comprising 129 CAI members and 41 IAS members) was the best that the Institute has enjoyed for some years.

A very fine display of photographs of the Arctic was kindly provided by the RCAF Photographic Establishment and was erected in the Registration Area, where it lent an effective background to the proceedings.

THE DINNER

The Dinner too, which took place on the 23rd October, was well attended – by recent standards – with 326 members and guests present. Here again the President introduced an innovation in proposing the toasts in French – "La Reine", an exclusively Canadian toast since 1793, and "Le Président des Etats-Unis". In a brief address the President welcomed the IAS members and read a cable from Dr. Ballantyne, as follows:

"The President and Council of the Royal Aeronautical Society send you greetings and best wishes for a successful Joint Meeting."

This message from the RAeS led him to the subject of the recent Anglo-American Conference, which he described as one of the finest international meetings he had ever attended; and he paid warm tribute to the hospitality extended by the RAeS to the CAI and IAS delegates. The President also mentioned that there was a possibility that a part at least of the next Conference, in 1963, would be held in Canada; if this materialized, it would entail a great deal of hard work by many members of the Institute to prepare a meeting appropriate to such distinguished guests.

The President (l) and Dr. James E. Mooney, Guest of Honour and Principal Speaker

Prof. G. S. Glinski, Vice-Chairman, Ottawa Branch, opening the Meeting

The President closed by announcing the result of the recent ballot on the change of the Institute's name and said that an application would be made to the Secretary of State as soon as possible to regularize the adoption of the name "Canadian Aeronautics and Space Institute".

In replying for the IAS, Mr. Charles Tilgner, Vice-President, brought greetings from his Institute and, personally, from its President, Dr. Guyford Stever, who had been unable to come to the Meeting. He recalled that, on the same occasion last year, Mr. Boyd, who was then President of the CAI, had taunted the IAS on their change of name from "Aeronautical" to "Aerospace"; at that time Mr. Tilgner had forecast that the CAI would make some similar change in "about a year or so" and he enjoyed rubbing it in now.

After a short intermission, the President introduced the Principal Speaker, Dr. James E. Mooney, Deputy US Antarctic Projects Officer, who, in addition to giving a short but most interesting talk, showed an excellent film entitled "Portrait of Antarctica"; it had been shown only twice before.

Dr. Mooney pointed out that this was the 50th Anniversary of the Amundsen and Scott expeditions, the first to reach the South Pole. In those 50 years a great deal of research had been done, but there was much remaining to be done and he was encouraged by the spirit of cooperation that inspired the scientists of many nations working there; he made special reference to Russian-American cooperation in Antarctica. The Speaker briefly reviewed the history of antarctic discovery, gave a number of those truly frightening statistics of temperatures, ice thickness and snowfall, and expressed his opinion that it would provide a suitable training ground for would-be space travellers!

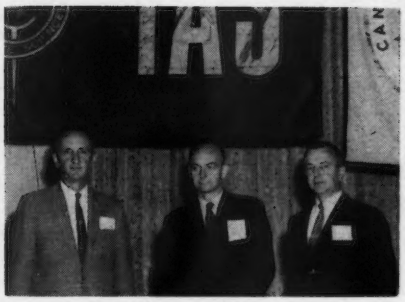
After the film, the President called on Mr. Boyd to move a vote of thanks. The film had shown the application of modern machinery to antarctic conditions – aircraft, sno-cats and a host of other children of our brain – but Mr. Boyd reminded the audience of the great explorers of the past, in both polar regions, and of the fact that regardless of the equipment at their command, the quality of the men was the dominant factor. He thanked Dr. Mooney and the US Navy for a splendid "portrait of Antarctica" today.

TECHNICAL SESSIONS

The technical sessions were devoted to the Operation of Aircraft, Polar Navigation, Engineering Considerations and a very satisfactory panel discussion on Search and Rescue.

Mr. Charles Tilgner, Vice-President IAS

Operations Session: (l to r) Mr. A. L. Bingham, Mr. P. D. Gillich, Mr. P. J. Lyons (Chairman), LCDR J. P. Croal, Mr. W. C. E. Loftus and Mr. H. B. Dees



Navigation Session: (l to r) Mr. E. C. Kendall (Chairman), Mr. E. S. Pedersen and Capt. W. B. Munson

Operation of Aircraft

The first session was opened by Professor G. S. Glinski, Vice-Chairman of the Ottawa Branch, who welcomed the members attending, especially those from the IAS, and expressed the hope that the Meeting would be a useful one. He then handed over to Mr. P. J. Lyons of TransAir Ltd., the Chairman of the session.

The three papers, entitled "Problems Associated with Transpolar Airline Operations" by Mr. A. L. Bingham and Mr. I. A. Gray of CPAL, "Flight Testing the C-130 Hercules in the Antarctic" by Mr. H. B. Dees and Mr. P. D. Gillich of Lockheed Georgia and "The Use of Helicopters in Polar Operations" by Mr. W. C. E. Loftus and LCDR J. P. Croal of Spartan Air Services, were presented in succession and a general question and discussion period followed. Mr. Bingham's paper (Mr. Gray was not present) stimulated quite a lot of discussion about the telecommunication problems encountered on the polar route. The Lockheed speakers supported their very interesting paper with a film entitled "Rendezvous 90° South" and discussed the problems of carrying out a test programme under the unpredictable weather conditions of the Antarctic and with no hangar facilities. And Mr. Loftus made a strong case for the helicopter in the support of scientific and development work in the otherwise inaccessible regions of the north and particularly stressed the value of the helicopter/ice breaker combination.

It was a good session attended by about 100 people.

Polar Navigation

The second session, held in the afternoon of the first day with Mr. E. C. Kendall of CPAL in the Chair, attracted an attendance of about 150. The first speaker was Mr. E. S. Pedersen of SAS, who spoke on "Transpolar Jet Navigation" and gave a very interesting account of the special problems encountered, the solutions which had been evolved and the trends for the future. He evidently was a master of his subject and took on all comers in the question period. He was followed by an excellent presentation by Capt. W. B. Munson USN (Retd) on "Naval Aviation in Antarctica". Capt. Munson's talk was not highly technical but was an entertaining report on the problems associated with the antarctic operation of aircraft, and it carried on in an informal discussion during the coffee break; later he answered a few questions from the floor. The final paper of the session was presented by Mr. A. W. Duguid of CDC; his subject was "Integrated Navigation Systems for V/STOL Aircraft" and, though it was an excellent paper, it was perhaps a little too technical for the majority of the audience. It also suffered from its position on the programme at the end of the day.

Search and Rescue

The morning session of the second day took the form of a discussion, led by a Panel, on the general subject of Search and Rescue. W/C W. C. Klassen was in the Chair. To set the stage, each of the members of the Panel gave a brief talk on his particular aspect of the subject and then, after a coffee break, the general discussion from the floor ensued. Mr. J. G. Brindle of the DOT listed the Canadian requirements for emergency equipment to be carried and the flight procedures to be followed by aircraft flying in the far north. Col. T. L. Shockley, USAF, described the organization, equipment and methods developed by the USAF to meet their search and rescue requirements, both local and global, and supported his talk with slides and a film. S/L S. E. M. Milliken, RCAF, outlined the RCAF commitments for search and rescue of civil aircraft and the equipment and organization employed; he illustrated his talk with a wall map of the Canadian north. Mr. R. E. Fulton gave what was perhaps the most spectacular presentation, showing an excellent coloured film depicting an aerial recovery system developed by his firm; in brief a kit is dropped to the stranded man, containing harness, which he puts on, and a balloon, which he inflates and sends aloft on a cable

The display of RCAF Arctic photographs

attached to the harness; the aircraft then snags the balloon cable, plucks the man into the air and draws him aboard. The last member of the Panel to speak was Mr. R. A. Houghton of Grumman, who presented an analytical study of search and rescue requirements by aircraft type and showed general aircraft performance curves on slides; Mr. Houghton's paper was a valuable one but suffered by following Mr. Fulton's fascinating film. The discussion that followed was very keen and W/C Klassen had to cut it off, unfinished, when time ran out.

Engineering considerations

The last session was concerned with engineering considerations and contained three papers, by Mr. T. G. Dunkin of Canadair, Mr. P. Hartline of TWA and F/L K. Weinstein of CEPE; Mr. F. C. Phillips of Canadair presided and there were about 60 present. Mr. Dunkin's paper was entitled "Considerations for Landing Aircraft on Floating Ice", an unusual study which stimulated some discussion. It included some information furnished by Dr. L. W. Gold of the Division of Building Research, National Research Council, and Dr. Gold himself contributed a short statement, confirming and amplifying some of this information. "Aircraft Maintenance in Polar Regions" was the subject of Mr. Hartline's paper, which provided an interesting contrast to F/L Weinstein's paper which followed it; the former indicated that, on the whole, the airlines had had relatively little cold weather experience and their basic principle was to keep the aircraft warm – they had to use it; on the other hand F/L Weinstein's paper, entitled "Some Aspects of Cold Weather Testing and Operation of Aircraft", described the very extensive RCAF experience in proving aircraft under arctic conditions – they let the aircraft get cold to test its capabilities. F/L Weinstein's was a very provocative paper but unfortunately it did not benefit from the discussion it deserved, because time ran out.

After Mr. Phillips had thanked the speakers and closed the session, the President made a few concluding remarks to adjourn the Meeting.

Copies of some of the papers presented at this Meeting may be procured from the CAI or from

The Institute of the Aerospace Sciences,
2 East 64th Street,
New York 21, N.Y.

INTERPLANETARY EXPLORATIONS SYMPOSIUM

THE Astronautics Section, co-sponsors with the Canadian Astronautical Society and the Institute of Aerophysics and David Dunlap Observatory of the University of Toronto, held a very successful symposium at the UTIA on the 26th and 27th October. The programme contained two sessions on Terrestrial Space, one on Lunar Space and one on Interplanetary Space and included two luncheon addresses, one on the medical aspects of space travel and one on the IGY. The Principal Speaker at the Dinner, held on the 26th October in the De Havilland Cafeteria, was Dr. I. I. Glass, who reported on his recent visit to the Soviet Union under the title "Aerophysical Research in Moscow".

Most of the visitors to Toronto stayed at the Westbury Hotel and a bus service was provided to take them to and from the UTIA on the northern outskirts of the city.

The first day's registration was 69 and a further 21 registered on the second day. Of this total of 90, 34 were members of the CAI.

Dr. I. I. Glass delivering his address at the Dinner on "Aeophysical Research in Moscow"

The meeting offered an opportunity for Mr. J. G. La Berge to display the postage stamps, commemorating the IGY and subsequent developments in space explorations, which he has been collecting on behalf of the Astronautics Section. The collection was mounted on a notice board provided by the UTIA just outside the lecture hall and it aroused a good deal of interest. A number of excellent photographs showing details of the Topside Sounder Satellite were also mounted, beside the stamp collection.

LUNCHEONS

On both days those attending the meeting adjourned to the De Havilland Staff Dining Room for lunch. On the Thursday Dr. J. J. Green was in the chair and the Principal Speaker was Dr. W. R. Franks who had chosen the attractive title "God's Image and Space Travel". His short talk reviewed the human machine, in engineering terms, giving an indication of its complications, strengths and weaknesses and concluded with a summary of Canadian contributions to research in aviation and space medicine – a not unimposing list.

Mr. F. R. Thurston was Chairman of the luncheon on the Friday, which was unfortunately not quite so well attended as that on the previous day. The Speaker was Dr. J. T. Wilson, who described, with slides, his travels during the IGY through Middle Europe, Russia, China, New Zealand, Antarctica and South America. He concluded that the great need of the underdeveloped countries was the Industrial Revolution, rather than Western morals and forms of government, and stressed the responsibilities of the scientist in the development of world society.

Terrestrial Space I: (l to r) Dr. D. C. Rose (Chairman), Prof. B. Etkin and Prof. V. C. Liu

DINNER

The dinner, which was attended by 61 people, was unfortunate in being held in too large a room but, apart from this sense of isolation, the event was enjoyable enough. It was moreover an event of some historical significance; Dr. J. J. Green, Vice-President of the CAI, and Dr. P. A. Lapp, Chairman of the CAS, jointly announced the Institute's election to change its name to the Canadian Aeronautics and Space Institute and the Society's intention to dissolve and merge its interests with the CASI. Dr. Green observed that the amalgamation of the two groups was a very timely and sensible step and Dr. Lapp, while referring to the successful joint meetings held in the past, said that there really was not sufficient astronautical activity in Canada to justify the existence of two societies with such similar interests. Both of them urged non-members engaged in the aeronautical and space sciences to join this now-united organization.

After this announcement Dr. G. N. Patterson, the Chairman, called upon the three guests from sister societies: Mr. Charles Tilgner, Vice-President of the IAS, Mr. Irwin Hersey, Director of Publications of the ARS, and Mr. J. E. Kennedy, National Secretary of the Royal Astronomical Society of Canada. Each congratulated the CAI and CAS for their decision to unite and expressed the hope for close cooperation between the CASI and the society which he represented. Mr. Kennedy added his congratulations to the sponsors of the symposium, which, he said, gave astronomers an appreciation of the need for closer collaboration with the aeronautical and space scientists.

Dr. Glass' talk on "Aerophysical Research in Moscow" opened with an explanation of the purposes and circumstances of his visit to the USSR this summer and then developed into a commentary on some extraordinarily fine slides of Moscow and Leningrad. Unfortunately, the dinner had started rather late, throwing the whole programme behind, so that time did not permit of any discussion, though Dr. Glass expressed his willingness to answer questions at the conclusion of his slides.

Dr. Heard moved a vote of thanks to the Speaker and the dinner was adjourned.

TECHNICAL SESSIONS

The technical sessions were opened by Dr. G. N. Patterson, Director of the Institute of Aerophysics, who extended a cordial welcome to all those attending and stressed the timeliness of the symposium in the light of Canada's increasing participation in the space sciences. He then handed the meeting over to Dr. D. C. Rose, Chairman of the NRC Associate Committee on Space Research, who was Chairman of the first session.

Terrestrial Space I

The first paper entitled "On the Determination of the Earth's Atmospheric Structure with Sounding Rockets and Artificial Satellites" was given by Professor V. C. Liu of the University of Michigan. Special emphasis was laid on pressure, density, temperature and composition measurements. Since these parameters are often measured indirectly with the aid of atmospheric models and gas-dynamic principles, it is necessary to make a critical study of the validity and limitations of these gasdynamic methods in upper atmosphere research.

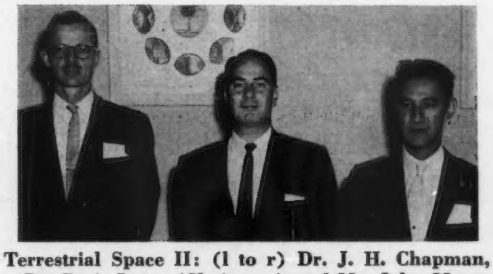
The second paper was an enlightening review of the principal dynamic and thermodynamic characteristics of the atmospheric entry of manned space vehicles; it was entitled "The Entry of Manned Manoeuvrable Spacecraft into Planetary Atmosphere" and was presented by Professor B. Etkin of the University of Toronto. Bearing in mind the temperature and acceleration limits that humans can endure, he discussed the advantages of aerodynamic lift for control of the flight path. Lifting vehicles have a very real advantage over ballistic vehicles since a much larger margin of error can be allowed in the approach path, and the difficulties of landing at a pre-selected spot are not nearly so severe.

Terrestrial Space II

The second session was held under the Chairmanship of Dr. P. A. Lapp, Chairman of the Canadian Astronautical Society, and dealt exclusively with the Canadian Topside Sounder Satellite. Dr. J. H. Chapman of the Defence Research Telecommunications Establishment gave the first paper, which was an interesting and revealing description of the programme. The satellite is designed to probe the atmosphere canopy from the top with radio waves in order to study the electrical properties of the uppermost regions of the atmosphere from 300 km to 1000 km. The satellite would be launched by NASA from the Pacific Missile Range in a near-polar orbit. The structural and thermal design problems were described by Mr. J. Mar of the Defence Research Board in a paper co-authored with Mr. H. R. Warren of De Havilland Aircraft of Canada Limited. The two extendable dipole antennas, 75 ft and 150 ft long, were the most striking features of the satellite. The solution to the difficult problems of packaging such long antennas into a satellite was all the more impressive by virtue of using simple engineering techniques in such a sophisticated manner.

Lunar Space

Dr. J. F. Heard, Director of the David Dunlap Observatory, presided at the first session on the second day. The first speaker was Professor D. A. MacRae of the University of Toronto who, with an hour-long show of impressive slides of lunar features, traced the history of the theories attempting to explain their formation. Audience participation was enthusiastic; the number attending this session swelled, and many participated in the lively discussion following the paper. He was followed by Mr. B. Milwitzky, of NASA Headquarters, who spoke



Terrestrial Space II: (l to r) Dr. J. H. Chapman, Dr. P. A. Lapp (Chairman) and Mr. John Mar

Lunar Space: (l to r) Mr. B. Milwitzky, Dr. D. A. MacRae and Dr. J. F. Heard (Chairman)

Interplanetary Space: (l to r) Dr. J. A. Giordmaine, Dr. I. I. Glass (Chairman) and Mr. R. C. Moore

on "The NASA Program for Unmanned Exploration of the Moon" and described Project Ranger and Project Surveyor, the early scout vehicles that will land on the Moon. They will sample the soil for gas content, radioactivity etc, test for an atmosphere and magnetic field and perform a host of other functions. It seemed rather startling to picture such a device from Earth sitting on the Moon, drilling down quietly and sending information back on its findings. A colour film depicting the landing of a surveying vehicle and the automatic performance of its duties was shown later on in the day. It was a high point of the symposium and was very well received.

Planetary Space

For the final session Dr. I. I. Glass, Chairman of the CAI Astronautics Section, was in the Chair. (It will be noted that the senior Officers of the sponsoring organizations had each taken their turn of Chairmanship in the course of the Symposium.) The first paper entitled "Atmosphere and Surface Conditions of Venus and Mars" was presented by Dr. J. A. Giordmaine of the Bell Telephone Laboratories, who gave a comprehensive review of the knowledge gained about the atmospheres of Mars and Venus by use of visual and radar techniques. He mentioned the difficulties presented by the heavy cloud cover on Venus when deciding on the thickness of the atmosphere and just how far down the surface is. He held out small hope for those who might expect reasonable amounts of oxygen in either atmosphere.

The programme concluded with a paper from Mr. R. C. Moore of NASA, on the subject of "Scientific Investigation of the Regions beyond the Moon". It was a most interesting account of the reasons for investigating space and how the investigation is to be carried out. The instrumentation for the early Mars and Venus probes and some of the difficulties faced were described. He reviewed the results of the successful interplanetary probes and outlined plans for future probes into the solar environment and out of the ecliptic plane.

Finally Dr. Glass closed the session with a few words of thanks to all the speakers and the audience for a very useful and stimulating symposium.

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